TROPICAL AGRICULTURE

THE OFFICIAL JOURNAL OF THE
IMPERIAL COLLEGE OF TROPICAL AGRICULTURE

VOL. XXIII No. 3 MARCH, 1946 PRICE 6d.

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THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE, TRINIDAD, B.W.I.

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THE UNITED NATIONS FOOD AND AGRICULTURE ORGANIZATION*

AN international department of agriculture, the United Nations Food and Agriculture Organization, was inaugurated at the Quebec Conference last October. The Constitution of the Organization was formally signed by representatives of forty-two countries. A programme of action was evolved and approved at the meeting. It provides for world-wide activities on many phases of the twin problems of increasing the efficiency of production and facilitating the distribution of food and other agricultural products.

Much emphasis was placed at the Quebec Conference upon the need for stimulating better use of present food supplies, in order to increase the nutritional status of the people of all nations. To this end, the Food and Agriculture Organization propose, at an early date, to make a rapid survey of available food resources and of the requirements of various countries. The immediate purpose of such a survey will be to provide the basis for recommended international movements of food to areas of greatest need and to stimulate the early production of foods in short supply. A large section of the world's population is chronically poorly fed, and the situation has been aggravated because of the war. Stress will be laid at all times upon the improvement of the diet of the so-called "vulnerable" groups, such as school children and nursing mothers. In parts of the world, means will be sought to increase the supplies of "protective" foods—milk, vegetables, fruit, and eggs. Positive action in improving dietary standards requires joint action of agricultural and food groups with other groups—public health, education, and social service agencies—at both the national and international level. The Organization will sponsor national nutrition agencies to develop this work at a national level, and it will co-operate with similar agencies at the international level in working out a united approach.

The Organization is pledged to the development of agricultural research. It recognizes the substantial advances made in recent years in many countries in increasing crop and livestock production and deplores the lack of progress in many countries where populations press heavily upon the food supply. It will seek therefore to stimulate national efforts in capitalizing on scientific progress and, over and above this, to devise means whereby progress will be internationalized.

*Abridged from an article by J. A. Becker, *Foreign Agriculture*, 10, 1-6, 1946.

Beneficial experimentation results in one country should point the way to increased production and utilization in others. Only by concerted action can the nations profit by one another's advances. The Organization assumes responsibility for this important task.

Particular emphasis was placed upon the need for spreading the results of research, not only within countries but also among countries, so that people throughout the world may benefit from national progress. In furthering the application of scientific advancement to the problems of agricultural production, a long list of recommendations was approved at Quebec. The list included the establishment of a bibliographical service for the dissemination among workers of reports of progress in their fields, the promotion of publications, and the development of internationally recognized standards or units. Especial attention was directed to collaboration among national agencies, exchange of information relating to improved feeding standards for livestock and poultry, and to the application of modern techniques for the control of insect pests and diseases of both plants and animals.

The problems of agricultural production with which the Organization will be concerned are many and varied. Attention will be given to the development and conservation of soil resources through forest clearing, improved management of range land, irrigation, and drainage. Often the solution to such problems requires public action, and an international agency, such as the Food and Agriculture Organization, may focus favourable attention upon them.

The Conference emphasized the inability of agriculture to stand alone. It pointed to the interdependence of industry and agriculture and urged the nations to make a searching appraisal of their current status. Some might well take definite action to find in industry a place for excess agricultural man-power and to study joint industrial-agricultural developments whereby workers will have all year-round employment. These recommendations were closely allied with those relating to credit. Nations were urged to establish policies designed to provide needed credit at reasonable terms to farmers, forest owners, fishermen, and governmental undertakings servicing agriculture while, at the same time, discouraging uneconomic borrowing and encouraging orderly debt repayment.

The importance of fish as food was given great emphasis at the meeting, and a warning was sounded that, unless constructive international action was taken, the resources of the sea might be depleted by overfishing, such as took place after the first world war. There is urgent need for exploration of waters, the potentialities of which as a source of supply are still unknown, in order that increased supplies of this valuable food may be made available without exhausting fish resources in better known waters. Because the oceans are still international, the Food and Agriculture Organization will have an especially significant rôle to play in the fishery industry.

Forests and forest products came in for extensive discussion at the Conference. A programme was outlined by which the Organization might help in preventing destructive exploitation of the forest resources of the world through the stimulation of good forest-management practices. Stress was placed upon the need for more general application of the results of research in improving wood-utilisation processes.

Problems relating to national and international marketing of agricultural products of all kinds, including fish and forest products, were discussed at length and made the subject of a number of specific proposals. One proposal was that the Organization should study and make suggestions concerning the diminution of trade barriers and the improvement in distribution of food products to the end that stocks would not accumulate in some countries while the populations of others were underfed. Basic to the study of problems of production and distribution is the knowledge of underlying facts. The Conference therefore authorized the collection and compilation of statistics covering the whole field of food and agriculture. A programme of statistical and informational reports was outlined, whereby the Organization might be in a position to ascertain the most pressing problems in the various fields with which it will deal.

The annual budget of the Organization is $5,000,000, which is much less than is spent in agricultural research alone in many of the countries which subscribe to the constitution. Obviously, therefore, the Organization cannot function in the manner in which departments of agriculture function in the individual countries. In point of fact, to do so might be said to impinge upon the sovereignty of nations. Many of the activities of national departments of agriculture involve standardization, inspection and regulation. All such activities are clearly outside the scope of an international body such as the Food and Agriculture Organization, which would have advisory and consultative functions. It will serve as a clearing house not only for information but for the interchange of technical workers.

Great stress was laid upon the need of organizing technical missions, whereby a country may obtain help from the staff of the Food and Agriculture Organization, or from specialists from other countries, in solving problems in agricultural research and education. The fields of work in which the Organization might be active range from obtaining the services of an extension worker to demonstrate improved methods of food preparation to the planning of such agricultural-industrial developments as the Tennessee Valley Authority in the United States. An important instrument for pooling developments in agricultural science will be the creation of rosters of technical experts and the formation of standing committees of specialists to whom the national agencies may come for assistance in meeting specific problems.

The fields of work of an international organization of this kind are so numerous that only matters of extreme urgency can receive attention. The

delegates of the nations attending the Conference realised this full well. While they made certain specific recommendations with respect to matters which would need early and forceful attention, in the main they delegated authority to the Director General and the Executive Committee to determine which projects will be undertaken and the relative emphasis to be placed upon each. The over-all programme of the Organization is a long-time programme, looking ahead to the gradual development of increased efficiency in the production of agricultural products, distribution of these products, and their utilization by the consumer. The means of this improvement are many and varied—agricultural experimentation, food chemistry, improved education of youth, expanded programmes of adult education, and the support of programmes looking to increased industrial activity in countries where, at present, too large a proportion of the people live upon the land and obtain their living solely from it.

Like any other conference, international, national, or sectional, the Quebec Conference gave voice to altruistic aims, stated in lofty, general, and sometimes vague terms. It was not an initial conference, however, and it did not confine itself to the framing of resolutions and recommendations. For food and agriculture, this necessary preliminary step had been taken at Hot Springs in May, 1943. The Quebec Conference had as its purpose the development of policies and a programme for putting the Hot Springs recommendations into effect. Anyone reading the report of the Quebec meeting will find in it an admixture of the theoretical and practical. While the objectives outlined may be beyond the hope of immediate or near-future attainment, the programme includes enough specific suggestions of "what to do" and "how to do it" to guide the initial steps of the Organization in the right direction.

CONSTITUTION IN CATTLE IN RELATION TO PESTS AND DISEASES *

BY

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THE genetic relation of animals to their pests and diseases can best be illustrated by what happens when European cattle are introduced into the tropics. There they are extremely susceptible to local pests and diseases to which the native or other tropical cattle are comparatively resistant.

European cattle in the tropics have a higher incidence of tick infestation than the Zebu, which is probably due partly to their longer hair (Kelly, 1943) and to their higher body temperature. There is considerable variation in the length of hair in European cattle in the tropics (Bonsma, 1943) and there is also some evidence of segregation of this character in European-Zebu crosses (Hammond, 1932).

The degree of tick infestation regulates the intensity of infection by the piroplasmosis of tick fever. In Zebu cattle there is no evidence for any immunity to infection. The main difference between European and Zebu cattle lies in the fact that the resistance to the effects of infection is very much higher in Zebu than in European cattle (Kelly, 1943); first crosses come nearer to the Zebu resistance (Fronda, 1930).

An explanation of these facts is that the nutritive state of the body depends on the power of heat regulation of the animal: where this is defective and a low nutritive state exists the power of resistance to infection by piroplasmosis is low. Rhoad (1941, 1942) has measured the body temperature and dissipation of energy, as shown by increased respiration rate, in crosses and backcrosses between the Zebu and European cattle. The milk production and growth of these crosses and backcrosses run parallel with their resistance to tick fever and there can be little doubt that they are all due to differences in physiological constitution mainly connected with the heat regulation powers of the animal at high air temperatures. For tropical conditions new breeds—the Santa Gertrudis (Rhoad, 1941); the Philamin (Fronda, 1930, Manresa, 1934) are being formed to combine the productive powers of European beef cattle with the heat, tick and disease-resisting qualities of the Zebu.

Little experimental work on the 'physiological constitution' of cattle has been done in this country and only speculations can be made on the basis of practical experience. There is some experience to show that genetically high milk producing cows have reduced resistance to diseases when nutrition conditions are poor. The intensity of competition of the udder with the other tissues of the body for incoming nutrients is determined by genetics and this in turn determines resistance to disease at low nutritive levels, although not necessarily at high nutritive levels.

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SEASONAL FLUCTUATIONS OF SOIL MOISTURE AND NITRATE IN A HUMID TROPICAL CLIMATE (TRINIDAD, B.W.I.)

BY

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(I) Introduction

This article presents and discusses data obtained by the application of routine laboratory methods to soil samples periodically collected within an area of land typical of the College Farm. The main object of the investigation was to trace the fluctuations of available soil moisture and nitrate-nitrogen in cultivated soil subjected to variable rainfall. The work was undertaken as part of the training of first year diploma students of the classes of 1933-34, 1934-35 and 1935-36, to whom credit is due for the measurements of soil moisture. Soil constants and nitrate contents were determined by the staff of the Chemistry Department of the College under the supervision of Mr. G. Rodrigues. Rainfall data were abstracted from the records of the College Meteorological Station under the charge of Dr. E. C. Humphries. Thanks are due to these colleagues for providing essential information.

The rains that fall over the College area are confined mostly to wet seasons of seven months' duration (June to December), the rest of the year being relatively dry. The rainfall is very erratic both in successive years and in corresponding months of different years; consequently soil moisture fluctuations are rapid. Presumably therefore the amount of available soil nitrogen will also fluctuate greatly, depending on the balance between nitrate production and nitrate loss by leaching. This balance will obviously be affected by the presence or absence of a growing crop so that its determination should involve comparison between fallow and cropped land.

(II) Experimental Procedure

Plots: The site of the experiment was a jib at the northern end of Field 11, College Farm; this was divided into four plots of equal size, each 72 square yards in area. Two plots were kept fallow throughout and two were kept continuously growing maize as far as the seasons would allow. Weeds were checked by frequent hoeing. The experiment was started in October, 1933, when the first crop of maize was planted on two alternate plots. On the east side of a fence bordering the plots, a strip of old pasture (*Axonopus compressus*), forming part of the College Savanna, was reserved for comparison with the fallow and the cropped plots. The grass is periodically machine-mowed and has formed a fair sward. The fallow and the maize plots were treated with small dressings of sulphate of ammonia (S/A) in mid-October and late December, 1934, and in late October, 1935, in order to maintain fertility.

Sampling and analysis: The soil of the fallow, cropped and pasture plots was separately sampled about once a month throughout a 33-months' continuous run covering the greater part of three wet and three dry seasons. Ten-spot composite samples were procured by means of a screw auger from each plot at 0-4 ins. and 4-10 ins. depth, the first corresponding with the thickness of the main rooting zone of maize on this kind of soil. The top and subsurface spot samples were collected in enamelled pails provided with lids. They were quickly mixed and subsamples taken in cigarette-tins whose lids were at once sealed with adhesive tape. *Soil moisture* was determined in the subsamples by weighing and drying in the oven. *Nitrate* was immediately determined on the residues from the tinned samples by a conventional colorimetric method, using phenol disulphonic acid reagent.

The remainder of the residues from the samples was accumulated and the bulk used for the measurement of soil constants.

Rainfall data: These were abstracted from the daily charts made by a syphon recording rain gauge installed at the College Meteorological Station situated about one quarter of a mile east of the plots.

(III) Description of the Soil

Relationships: The soil of the College Farm is derived from colluvial and alluvial detritus originating in the quartz-mica schists which comprise most of the western part of the Northern Range of Trinidad. The College is situated within one mile of the base of the southern foothills of this range where the colluvial fringe slopes gently southwards, eventually passing under the more recent swamp and lagoon deposits forming the Caroni Plain. The detritus is coloured yellow, orange or brick-red and consists mostly of irregular layers of sand and gravel. The soil-type has provisionally been named Maracas Sand (detrital phase); it is very variable with regard to texture and content of gravel, which tends to occur in lenses showing sporadic horizontal and vertical distribution.

Drainage features: The depth of the permanent water-table at the College Farm is around 20 to 25 ft. as indicated in wells dug by peasants whose holdings are situated on the western boundary. It does not appreciably fluctuate throughout the year.

Physical features: Laboratory data for representative soil of the plots and pasture are given in Table I; they were procured by routine methods in vogue in the College Chemistry Department.

Table I

Laboratory Data for Plot Soils

Plot.	Physical Constants				Chemical Constants					Nitrification Status	
	Sand coarse : fine		Index of texture (I.T.)	Wilting coefficient	Reaction pH	Org. matter (O.M.)	Total nitrogen (N)	C/N ratio	Av. P_2O_5	Av. K_2O	Incubation, 4 weeks at half satn. moisture (*a*) (*b*)
	per cent.			per cent.		per cent.			p.p.m.		p.p.m.
(A) Fallow : Top ...	9.1	61.6	18	10.2	6.8	2.24	.16	8.1	33	61	36 281
Sub ...	9.8	66.7	17	9.9	6.7	1.93	.14	8.0	15	54	34 285
(B) Cropped : Top ...	9.2	59.1	15	8.8	7.0	2.12	.15	8.2	43	82	33 311
Sub ...	9.7	65.5	16	9.3	7.1	1.82	.13	8.1	18	56	24 285
(C) Pasture : Top ...	10.0	56.0	14	8.0	7.2	2.65	.17	9.1	18	72	55 450
Sub ...	9.0	51.4	15	8.6	6.9	1.59	.11	8.4	17	80	43 386

(*a*) Fresh sample ;

(*b*) Sample *plus* ammonium sulphate and calcium carbonate.

The data for physical composition show that the soil consists mostly of fine sand (particles 0.20-0.02 mm. diameter).

Index of texture (sticky point moisture content *minus* one-fifth coarse and fine sand) varies from 14 to 18 per cent. The *wilting coefficent* similarly varies from 8 to 10 per cent., as determined in cultures growing maize seedlings, the values obtained being checked by the Briggs-Shantz formulae.

Chemical features : The soil is nearly *neutral* in reaction, having previously been limed. *Organic matter* and *total nitrogen* contents are medium-low for forest and cacao soils but medium-high for sugar-cane soils. *Carbon-nitrogen ratios* are relatively very low except for the pasture topsoil. Soils containing thoroughly humified organic matter have C/N ratios around 10.0, whereas the ratios for these soils are nearer 8.0, denoting either considerable loss of surface soil by erosion, or deterioration in biological condition which has not been corrected by adequate additions of fresh high-ratio plant residues or oganic manures. Available *phosphate* contents are medium-low to medium in amount and available *potash* is low. *Nitrification* values for incubated soils are medium to fairly high, showing that the soils are capable, not only of readily nitrifying their own organic nitrogen, but also of nitrifying considerable quantities of added ammonium salt.

(IV) Rainfall

The mean annual rainfall at the College for the past 21 years was 68.5 ins. though in one year (1934) it was as low as 50.6 ins., and in another (1927) as high as 104.7 ins. The rainfalls of the four years included in this investigation were: 1933, 87.2 ins.; 1934, 50.6 ins.; 1935, 64.4 ins. and 1936, 77.1 ins.; average 69.8 ins. Thus the rainfall was well above the 21 years' mean during the first and fourth years (+18.84 and +8.44 ins. and below the mean during the second and third years (−18.00 and −4.04 ins.). The second year's (1934) rainfall was the lowest on record at the College. These facts are important in connection with nitrate fluctuations. The mean monthly rainfalls also vary greatly. About 85 per cent. of the annual rain usually falls within seven wet-season months, but the rains may come early (as in 1933, 1935 and 1936) or late (as in 1934). There is a diminution in rainfall during September or October (the "petite carême"). The dry season generally sets in towards the end of January in most years.

Rain showers within the area vary greatly in intensity, as revealed by the daily records of the rate of fall. They have been sub-divided arbitrarily into "light" showers, "medium" showers and "heavy" or "torrential" showers. Convenient limits for these have been suggested by W. G. Wells* for the rainfall of the Cotton Belt of Queensland, Australia, where it has been found that rain which falls as showers of intensity 0.40 ins. per hour or less evaporates without penetrating the soil. At the other extreme, rain which falls as showers of intensity 0.75 ins. per hour or more runs away without penetrating. Thus, only rain falling as showers of intensity between these limits is believed to enter the soil and so to become "effective" as a factor in plant growth.

* *Ann. Prog. Repts. Expt. Stations,* Emp. Cotton Growing Corp., 1941-42; 1942-43, p. 7.

Table II

Analysis of Monthly Rainfalls

Sub-division into torrential, medium and light showers ; number of each per month and total amount of rainfall in each category.

Total rainfall	1933						1934						1935						1936					
	87.2 ins.						50.6 ins.						64.4 ins.						77.1 ins.					
	Torrential		Medium		Light		Torrential		Medium		Light		Torrential		Medium		Light		Torrential		Medium		Light	
	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.
WET SEASON																								
June ...	3	1.2	11	3.7	42	7.5	—	—	2	0.1	26	1.1	1	0.2	5	1.7	24	1.9	8	2.2	15	3.1	44	7.5
July ...	5	2.0	11	3.3	63	7.2	—	—	3	0.5	30	3.3	4	2.3	8	1.7	40	3.7	2	0.6	14	2.7	61	7.4
August ...	4	4.0	5	2.0	32	5.2	6	2.9	6	1.3	26	3.1	4	2.5	9	3.4	34	7.9	7	2.8	7	3.9	34	3.7
September ...	5	4.0	3	2.2	24	6.1	2	2.0	7	1.5	24	3.3	6	2.7	4	2.5	32	8.6	4	3.3	5	1.2	31	5.2
October ...	3	5.2	—	—	22	3.0	5	3.7	6	1.2	36	6.1	2	2.0	4	1.5	14	2.1	2	1.4	8	2.1	21	1.6
November ...	4	1.0	6	1.5	42	5.2	5	1.2	2	0.7	34	9.9	1	0.4	6	2.2	35	3.6	3	3.3	6	1.3	46	4.1
December ...	2	1.5	5	1.1	30	6.9	3	1.2	3	0.5	28	2.4	2	0.4	6	0.9	38	3.8	1	0.3	5	1.3	53	5.3
Totals ...	26	18.9	41	13.8	255	41.1	21	11.0	29	5.8	204	29.2	20	10.5	42	13.9	217	31.6	27	13.9	60	15.6	290	34.8
DRY SEASON																								
January ...	—	—	1	0.1	21	4.0	—	—	—	—	24	1.7	—	—	—	—	11	0.7	—	—	5	1.7	14	0.7
February ...	1	0.1	1	0.1	15	0.5	—	—	—	—	20	0.8	—	—	—	—	14	0.5	—	—	—	—	23	1.0
March ...	—	—	2	0.2	22	1.0	—	—	—	—	7	0.5	—	—	—	—	19	0.9	—	—	1	0.3	5	0.2
April ...	1	0.1	—	—	13	1.6	—	—	—	—	3	0.2	—	—	1	0.1	6	0.2	1	0.4	4	0.7	26	1.2
May ...	2	1.5	4	0.9	21	3.3	—	—	1	0.1	22	1.4	—	—	6	1.4	33	4.7	1	0.5	5	2.6	28	3.5
Totals ...	4	1.7	8	1.3	92	10.4	—	—	1	0.1	76	4.6	—	—	7	1.5	83	7.0	2	0.9	15	5.3	96	6.6
Rainfall (ins.)...	20.6		15.1		51.5		11.0		5.9		33.8		10.5		15.4		38.6		14.8		20.9		41.4	
Percentage ...	24%		17%		59%		21%		13%		66%		16%		24%		60%		19%		27%		54%	

Note : *Torrential* showers, rate of fall over 0.75 ins. per hour.

Medium showers, between 0.75 and 0.41 ins. per hour.

Light showers, below 0.41 ins. per hour.

In order further to characterise the rainfall of the College area, the records have accordingly been analysed on Wells' scheme. The results are given in Table II and in the diagram. They reveal the following facts:—(*a*) Most of the rain (about 60 per cent.) falls as light showers; there are usually between 200 and 300 of these in a wet season and between 75 and 100 in a dry season. (*b*) Of the remaining rain (40 per cent.), about half falls as medium showers and half as torrential showers; there are usually between 30 and 60 medium showers in a wet season and up to 15 or 20 in a dry season. (*c*) Torrential showers are least numerous, there being between 20 and 30 in a wet season but few or none in a dry season.

(V) General Meteorological Conditions during the Period of the Investigation

Relevant data for meteorological factors at the plot sites during the period of the investigation (Nov. 1933 to May, 1936) are given in Table III. These data are separately summarised for wet season months and dry season months; they include figures for the following factors:—

(1) *Mean monthly rainfall.*—This averaged 7.48 ins. for the wet months and 1.73 ins. for the dry. Ignoring the unusually wet May months of 1935, 1936 and 1937, the mean dry season rainfall was only 0.98 ins.

(2) *Number of rainy days in the month.*—This averaged 20 days in the wet season and 12 in the dry.

(3) *Number of hours of sunshine.*—This was about 7 per day during the wet season and 8 per day during the dry which is not very much greater and may be accounted for by the greater degree of cloudiness in the wet season.

(4) *Air temperature.* — Maximum shade temperature showed no great differences between the seasons, averaging 86°F. throughout. Mean minimum shade temperature was two degrees higher for the wet months as compared with the dry (71°F as against 69°F).

(5) *Humidity.*—Only minimum relative humidity figures are given in the table; they show higher values for the wet months (average, 62 per cent. as against 55 per cent. for dry months.) The air becomes saturated practically every night a few hours after sundown and remains so until dawn, even in the dry season. Dew is thus deposited almost nightly.

(6) *Wind velocity and duration* are much higher and the wind more persistent in the dry months than in the wet. The values in the table are average "run of the wind" in miles per hour as measured on a speedometer geared to vanes rotating horizontally.

(7) *Evaporation.*—This was measured by a battery of three Livingston white porcelain bulb atmometers. The figures are cubic centimetres of water evaporated per month per bulb; they show considerably higher values (40 per cent. greater) for the dry season than for the wet.

Table III

Meteorological Data for the Period of the Investigation

(Monthly values)

	1	2	3	4		5	6	7		8	9	
Duration of seasons (mths.)	Mean monthly rainfall (ins.)	No. of rainy days per month	No. of hours of sunshine per month	Shade temperature Max. (°F)	Min. (°F)	Humidity Min. (%)	Wind velocity (m.p.h.)	Evaporation Atmometer (white bulb) (cc. mth.)	Open pan (ins. mth.)	Radiation Atmometer (black bulb) (cc. mth.)	Soil temperature (3 ins. dpth.) Max. (°F)	Min. (°F)
WET SEASONS												
(1) 3 ...	8.47	23	192	85	71	64	1.6	576	5.88	394	84	78
(2) 7 ...	6.55	19	223	87	71	61	2.4	829	8.46	645	88	78
(3) 7 ...	7.99	20	214	86	71	65	1.9	737	7.52	522	86	74
Means* ...	7.48	20	213	86	71	62	1.9	747	7.62	550	87	77
DRY SEASONS												
(1) 5 ...	0.94	12	239	85	68	53	3.2	1057	10.78	785	84	74
(2) 5 ...	1.71	11	242	86	69	54	2.9	1057	10.78	544	93	72
(3) 5 ...	2.54	14	240	86	69	58	2.4	997	10.17	513	84	73
Means* ...	1.73	12	240	86	69	55	2.8	1037	10.58	614	87	73

* Weighted

Evaporation was also estimated for a free water surface by multiplying the atmometer values by a calibration constant (namely, 1.02) determined in a comparative 8-weeks' run against an open pan evaporimeter during the unusually dry weather of September to November, 1944. Evaporation depends partly on relative humidity (saturation deficit) and is thus controlled by air temperature, but it also largely depends on air movement where the evaporating surface is exposed to wind.

(8) *Radiation.*—This was estimated as the difference in rate of evaporation between 3-unit batteries of Livingston black and white bulb atmometers. The figures indicate considerable variations for the different wet and dry season months.

(9) *Soil temperature* at a depth of 3 inches fluctuated considerably, being particularly high (93°F) in the second dry season (1935) presumably because the shallow surface layer of the soil dried out during that period.

(VI) Soil Moisture

(1) *Available soil moisture*

The detailed soil moisture and nitrate data which form the essential experimental results sought after in this investigation, are presented in Table IV and set out as graphs in the diagram. Therein the moisture data are given as "available" moisture content, that is, the amount of water (expressed as weight percentage of oven-dry soil) in excess of that which the soil holds by a force equal to the absorptive force exerted by living plant roots. Plants reduce the moisture content of a soil in which they are growing down to the point where they can abstract no more water; this is the "wilting point" and the amount of water left in the soil provides a measure of its "wilting coefficient". The magnitude of the wilting coefficient varies for different soils, being greatest in highly collodial soils. It may be determined directly in plant cultures or estimated from physical soil constants. It approximates numerically to between 0.5 and 0.6 times the index of texture.

For the College soil, the wilting coefficient averages 9 per cent. (range, 8.0 to 10.2; Table I). Its value for each plot soil, top and subsurface layers, has been subtracted from gross moisture contents so as to deduce the available soil moisture figures.

(2) *Effective rainfall*

In order to maintain a regular supply of available moisture within the rooting zone of plants growing in soil, a certain fraction of the total rainfall must gain access to that layer and penetrate to its base or deeper, thus becoming "effective" as a factor in plant growth. The quantity of the effective rainfall (F) is decided by the magnitudes of the following factors:—(1) the total amount of rain (T); (2) evaporation (E) from leaves and soil; (3) surface run-off (R), and (4) deep penetration (D) below the limits of rooting.

$$\text{Thus } F = T - (E + R + D)$$

The water relations of the soil are dynamic, however, and not static as this equation suggests. After a period of drought, the first showers that fall in a wet season yield sufficient effective rain within a certain time to saturate the soil. Thereafter the "duty of the rain" is to replenish lossess within the rooting zone caused by deep penetration (drainage) and by water-uptake by the living plants. It is important in ecological studies to reckon rainfall in terms of quantity per unit time, hence the need for analysis of rain showers into different rate categories. The three factors, evaporation, run-off and deep penetration, are dependent on the physical features of the soil; they too should be expressed as rates of water movement.

(*a*) *Evaporation.*—This is a highly variable quantity difficult to assess, particularly since it is greatly influenced by the presence of vegetation. Evaporation from soil is always less than that from a free water surface, except when the soil is saturated and water lies over it. The nature of the soil surface and of the shallow surface layer partly determines the rate of evaporation according to the degree of protection they afford.

At the experimental site, the evaporating capacity of the air throughout was very high, particularly during dry seasons when wind velocity was greatest. The amount of evaporation from a free water surface in an open pan was found to be not much less than the total rainfall during the wet season and greatly in excess of it during the dry season (Table III).

(*b*) *Run off.*—This depends partly on slope and partly on soil features, since it represents the surplus of unevaporated water that fails to penetrate into the soil.

At the experimental site, surface run-off from the cropped and fallow plots, though not from the pasture plot, was provided by shallow trenches dug between and around them. The land is flat and the surface somewhat irregular through tillages, so that water tends to lie in the hollows until absorbed by the soil or evaporated into the air.

(*c*) *Water penetration.*—Penetration of water into a soil is decided solely by physical soil factors. It is greatly enhanced when the soil surface has high infiltrability due to an open crumb structure or a cover of spongy humified organic matter. On the other hand, low permeability of soil and parent material, or the presence of an impervious subsoil layer (clay-pan, iron-pan or cemented soil) greatly retards downward penetration of water.

Permeability and free drainage of water are mainly dependent on the occurrence of "non-capillary" pore-spaces in a soil, that is, the larger pores including cracks, old root traces, insect tunnels and interstices between structure units or between discrete soil particles. In heavy clay soils lacking tilth, cracks provide the chief, if not the only, drainage channels, but in sandy soils, permeability is afforded mainly by the interstices between relatively large mineral grains.

Table IV

Rainfall, "Available" Soil Moisture and Nitrate Data

(Fallow, Cropped and Pasture)

From 2nd Nov., 1933 to 15th May 1936

Week	Rainfall	Fallow				Cropped				Pasture			
		Top		Sub		Top		Sub		Top		Sub	
	ins.	Water %	NO_3 p.p.m.	Water %	NO_3 p.p.m.	Water %	NO_3 p.p.m.	Water %	NO_3 p.p.m.	Water %	NO_3 p.p.m.	Water %	NO_3 p.p.m
Wet Season : 1933													
0	8.18	14.6	8.4	16.4	7.4	16.2	3.1	10.4	5.1	—	—	—	—
10	4.76	18.6	16.0	14.3	8.3	17.5	3.1	15.9	2.5	19.6	6.9	18.6	3.0
12	1.90	16.0	18.3	13.8	7.4	14.1	3.0	13.6	2.6	14.3	5.0	17.3	4.1
Dry Season : 1934													
18	0.68	9.4	20.8	8.2	6.8	3.7	2.6	6.4	3.2	6.4	4.9	4.5	3.5
22	0.44	6.6	25.9	3.3	8.4	3.6	4.1	5.2	3.1	4.5	2.8	2.7	3.4
29	1.28	5.2	59.0	5.2	31.1	2.9	18.0	5.9	11.1	9.9	13.7	9.4	9.3
37	2.70	5.4	49.1	8.2	18.5	6.2	19.2	7.8	8.8	12.8	16.2	13.3	18.0
Wet Season													
47	7.17	16.5	19.7	16.9	31.7	19.3	10.8	17.6	17.5	25.5	12.6	20.2	13.9
50	9.24	20.6	19.0	18.7	12.9	20.7	10.7	17.3	13.9	15.9	6.8	13.5	6.7
53	11.04	16.9	27.0	18.5	15.7	21.4	(32.9)	17.3	13.1	18.0	5.5	19.4	5.0
55	13.90	20.6	7.1	21.1	9.2	21.0	5.0	19.3	6.3	23.5	5.3	16.9	5.9
58	11.09	13.6	7.1	17.6	10.5	8.9	3.1	15.1	3.0	11.7	4.5	20.5	3.8
Dry Season : 1935													
63	1.95	8.1	25.6	10.7	12.7	9.1	29.6	10.9	8·7	5.8	8.6	8.0	7.5
66	1.20	8.3	17.6	10.9	10.3	11.1	26.1	10.5	4.2	12.8	5.8	12.0	2.3
70	0.88	7.4	31.3	7.6	13.1	2.0	25.2	4.5	12.7	3.0	11.2	3.4	9.2
76	0.80	3.6	60.0	7.6	26.2	2.4	60.0	3.0	24.5	6.1	5.5	3.9	8.1
78	0.64	2.4	63.0	6.1	21.7	2.2	44.1	2.6	15.9	0.0	12.2	0.0	6.8
81	1.05	6.9	60.0	9.3	(45.5)	6.4	41.1	8.4	25.5	5.4	12.0	7.7	9.0
Wet Season													
86	3.99	7.3	(44.5)	12.3	(33.5)	11.3	33.5	13.8	22.5	30.8	12.0	22.6	9.0
90	6.23	10.8	34.0	14.8	24.5	13.2	16.5	15.0	21.5	23.3	13.0	22.0	9.0
95	9.70	14.5	10.0	18.6	5.0	15.1	6.0	14.8	6.0	31.6	5.0	23.3	4.0
100	13.74	16.6	7.0	15.6	7.0	18.6	7.5	16.4	8.5	26.4	9.0	21.2	8.0
101	15.33	18.4	4.9	18.2	5.3	17.1	6.5	18.1	6.1	—	—	—	—
103	7.47	10.2	5.5	13.1	3.1	9.6	5.2	13.0	3.7	—	—	—	—
107	5.53	18.7	31.5	17.4	10.0	16.2	27.5	15.4	8.5	—	—	—	—
109	5.66	16.8	18.4	16.6	33.5	19.0	12.0	15.7	27.4	—	—	—	—
111	6.11	20.2	12.4	15.9	20.7	21.0	7.5	17.4	6.1	—	—	—	—
Dry Season : 1936													
114	3.03	13.8	3.7	12.9	6.3	14.6	2.9	14.2	3.6	—	—	—	—
116	3.86	11.9	10.4	15.3	7.7	16.4	4.4	13.9	3.0	—	—	—	—
123	0.72	4.7	13.8	8.8	13.0	5.7	15.3	10,1	7.4	—	—	—	—
128	2.41	8.6	39.2	10.8	22.7	5.7	24.0	10.1	9.4	—	—	—	—
131	1.64	3.0	32.7	6.1	18.4	0.3	24.1	6.4	11.1	—	—	—	—
132	3.52	14.4	23.8	14.0	22.0	14.8	13.0	16.7	15.9	—	—	—	—

Note: (1) The figures for water content are per cent. oven-dry weights of gross soil moisture *minus* the wilting co-efficient value (*i.e.* "available" water).

(2) Values above 21 denote super-saturation.

(3) Values between 21 and 13 denote lack of aeration.

(4) Values between 13 and 6 denote good growth conditions. They lie within the non-capillary range.

(5) Values between 6 and zero all lie within the capillary range where water-abstraction becomes increasingly difficult as the moisture content is reduced to wilting point (zero value).

The College soil, being a distinctly sandy type, offers relatively little resistance to water penetration, except when fully wetted during periods of heavy rain. Impeding layers are absent and subsoil drainage is favoured by the prevalence of subterranean gravel beds and a deep water-table. Penetration below the rooting zone thus depends mainly on the amount of rain-water which enters the surface of the soil.

(3) *Storage capacity*

Whether or no rain-water which has percolated into the soil surface will be sufficient in quantity to saturate the soil within the rooting zone and to provide a residue that penetrates deeply depends, not only on the factors already considered, but also on the storage capacity of the soil when freely drained. This is sometimes referred to as the "field capacity" of a soil. Its magnitude is chiefly determined by the capillary pore-space, that is, by the total volume of the smaller pores which mainly consist of minute vesicles occurring in micro-reticulate soil colloids. The amount of this colloidally-bound water is approximately equal to the index of texture value which may therefore be taken as a measure of field capacity.

The *total* pore-space of a soil, including both non-capillary and capillary pore-space, determines its "saturation capacity". When all the pores are fully occupied by water to the complete exclusion of air, the soil is described as waterlogged; plants rooted in it are liable to asphyxiation through lack of oxygen. Their roots can then no longer absorb water; the plants consequently suffer from "physiological drought".

It has been shown that about 10 or 12 per cent. of the non-capillary pore-space volume of a soil should be occupied by air in order to provide enough oxygen for root respiration. This therefore determines the upper limit of the "physiological range" of soil moisture.

The following average values have been established for the soil of the experimental plots which has been disturbed by tillage and thus rendered fairly uniform to 10 inches depth.

	(1) Volume per cent.	(2) Weight per cent.	(3) Equivalent total rain (inches) (10 ins. layer of soil)
Saturation capacity	40.6	30.0	4.06 ins.
Non-capillary pore-space	20.0	14.8	2.00
Capillary pore-space	20.6	15.2	2.06
Wilting coefficient	12.6	9.3	1.26
Physiological upper limit	30.6	22.6	3.06

(4) *Interpretation of the soil moisture data*

It is now possible to offer an interpretation of the moisture data in Table IV in terms of physiological values in view of the foregoing considerations. Since the tabulated data are weight percentages of *available* soil moisture, the average values for saturation capacity and field capacity become 20.7 and 5.9 per cent. respectively or roughly 21 and 6 per cent. Also, on this same scale, the non-capillary moisture range extends between 21 and 6 per cent., and the capillary range between 6 and −9 per cent. When the available moisture content approaches zero (wilting point), growing plants will suffer from true or physical drought; when it lies above 13 per cent. they may suffer from physiological drought. Soil water held within the non-capillary range (values above 6 in the table) is free to move under the influence of gravity though doubtless the process of drainage takes considerable time, exhibiting a lag which is likely to be especially well-marked in this fine, sandy, somewhat compacted soil.

(*a*) *Wet seasons.*—Considering first the three wet seasons, it will be noted that the soil was almost saturated on several sampling occasions and that the topsoil was then generally wetter than the subsurface soil, doubtless a manifestation of drainage lag referred to in the last paragraph. On other occasions in the wet seasons, moisture contents lay well within the non-capillary range and frequently above the physiological limit, implying inadequate aeration, inimical to healthy plant growth. For long periods at a stretch, the plants were evidently subject to incipient asphyxiation.

Once the soil was thoroughly wetted to the 10-inches depth by the early rains, the actual fluctuations in moisture content were not very great, averaging only about 3 per cent. by weight of water over the whole wet period, which is equivalent to about 0.41 inches of rain. This is numerically equal to a single shower falling in one hour at the lower limit of the "medium" category. To saturate the soil completely from a condition of drought (wilting point) would require 2.8 inches of percolating rain or about 4 to 7 "medium" showers. These quantities are relatively insignificant, so that, during wet seasons, there must be a large amount of deep penetration of water well below the rooting zone in this soil.

(*b*) *Dry seasons.*—Considering next the three dry seasons, it will be noted that soil moisture contents frequently approached wilting point toward the end of the dry season. The maize plants then became very limp and the pasture grass withered and turned brown. The values (especially those for the subsurface soils) often lay just above the capillary range (values above 6) for a large part of the early dry periods, but mostly the moisture content of the dry soil lay within the capillary range where it is firmly held and cannot move in response to gravity.

(5) *Differences between plots*

Moisture contents and moisture fluctuations were highest in the pasture plot; this may be explained by the relatively low infiltrability of the grass sod. Water persistently lies in clear pools on the pasture during rainy weather. The grass plants are apparently constantly in danger of asphyxiation, which they possibly escape by forming a spongy superficial mat having high porosity, not included in the sampling. Moisture contents were generally lower in the cropped plot than in the fallow plot, presumably because the growing maize plants abstracted and transpired considerable amounts of water from this plot and also intercepted some of the rain falling upon it. Moisture fluctuations were about the same in these two contrasted plots.

(6) *Differences between seasons*

That considerable differences occur in the actual moisture contents and the degree of moisture fluctuation in the plot soils between successive wet seasons and successive dry seasons, because of the vagaries of the weather, is demonstrated by the experimental data and clearly shown in the graphs. The dry season of 1934 was unusually long and severe as contrasted with the dry seasons of 1935 and 1936, the last being particularly short and mild. Similarly, the wet season of 1934 was much shorter in duration and included a much lesser amount of "medium" or soaking rain than that of 1935. These differences are reflected in the shape of the soil moisture graphs for those periods.

(VII) Soil Nitrate

(1) *General*

The determined values for nitrate contents (expressed as parts per million of nitrate-nitrogen) corresponding to the values for available soil moisture, are presented along with the moisture data in Table IV and in the diagram in which they are plotted in reverse position so as the more clearly to show their negative relationship with soil moisture.

Nitrate contents of the topsoil of the *fallow plot* were generally much greater in magnitude than those of the subsurface soil except during some short wet spells when downward leaching was the heaviest. In the *cropped plot*, uptake of nitrate by the growing plant evidently reduced the nitrate content, especially during periods of rapid growth. In the *pasture plot*, there was little difference between the nitrate contents of topsoil and subsurface soil, presumably also a plant growth effect.

The fluctuations between wet and dry season nitrate contents throughout were very marked, particularly in the fallow plot, though not so evident in 1936 when the dry season was relatively wet. They were never very marked in the pasture plot. During the driest spells, the nitrate contents of the top-soil of the fallow plot and of the cropped plot reached relatively very high magnitude, being frequently over 60 p.p.m. This is the same level as that which would be realised in theory by the addition of about 600 lb. (5½ cwt.) of ammonium sulphate manure per acre. During the wet seasons, nitrate contents were reduced to below 10 p.p.m. in the fallow plot and below 5 p.p.m. in the cropped plot and the pasture.

Ammonium sulphate manure, applied to the fallow and cropped plots on three occasions during wet weather, produced only temporary increases in nitrate content. The first application was made just before a short but extremely wet spell in November, 1934, and was apparently rapidly leached out after having produced a temporary rise in nitrate content. The second application was made at the end of December, 1934, and it may have helped to raise the nitrate status during the early months of the succeeding dry season of 1935. The third application was made at the end of October, 1935; at first it exerted considerable effect on soil nitrate contents but the unusually wet weather of the two months following reduced the nitrate status to low values in January.

(2) *Relationship between available moisture contents and nitrate contents.*

Weighted averages for available soil moisture and nitrate-nitrogen contents are brought together in Table V.

The mean nitrate-nitrogen and moisture values, 17 in number, for the topsoils of the three plots show a (negative) correlation coefficient of −0.537 which is significant at the 2.5 per cent. point, proving that, for the topsoil, the higher the available soil moisture content the lower the nitrate content in proportion. For the subsurface soil, the (negative) correlation coefficeint is −0.199, which is non-significant, implying that a disturbing factor is operative, possibly downward removal of nitrate in solution below the rooting zone during wet weather.

The mean nitrate-producing capacity of the soil of the experimental area as measured by incubation tests performed in the laboratory on representative soil samples is 37 p.p.m. of nitrate-nitrogen, both for top and subsurface soil. Magnitudes greater than this were frequently attained in the field in dry weather, implying a process of concentration of nitrate in solution in the soil-water through the drying out of the soil. On the other hand, during wet weather, much lesser values were recorded, indicating downward leaching, coincident with the periods when the soil was nearly saturated. In general, a slight lag tended to occur in the nitrate content of the subsurface soil as compared with that of the topsoil, as in the case of moisture content.

Fallow Plot.—The laboratory value for nitrate-producing capacity of the topsoil of this plot is 36 p.p.m. (Table I). This value was exceeded on 7 occasions in the field during periods when the soil moisture content mostly lay within the capillary range (mean nitrate content for these periods 53 p.p.m.). For the subsurface soil, the nitrate producing capacity is 34 p.p.m. but this value was never realised though it was approached on 5 occasions during periods when the soil moisture lay within the non-capillary range favouring loss of nitrate by diffusion rather than by free drainage.

Table V

Averaged " Available " Soil Moisture and Nitrate Data for Wet and Dry Seasons

Period Weeks	Monthly rainfall (average)	Fallow				Cropped				Pasture			
		Top		Sub		Top		Sub		Top		Sub	
		Water %	NO_3 ppm.	Water %	NO_3 ppm.	Water %	NO_3 ppm.	Water %	NO_3 ppm.	Water %	NO_3 ppm.	Water %	NO_3 ppm.
Wet Seasons													
(1) 16	5.26	17.3	14.4	14.8	6.3	16.8	3.1	14.2	3.2	18.7	6.6	18.4	3.2
(2) 21	9.22	17.1	17.6	17.9	21.5	18.5	9.4	17.3	13.2	20.9	8.9	18.9	9.4
(3) 30	7.93	14.1	21.6	15.7	12.8	15.3	15.5	15.2	12.8	28.3	9.6	22.3	7.4
Means	7.47	*16.2*	17.9	*16.1*	13.5	*16.9*	9.4	*15.6*	9.8	*22.6*	8.4	*19.9*	6.7
Dry Seasons													
(1) 25	1.46	6.5	41.4	6.6	17.6	4.3	12.5	6.5	7.2	9.1	10.6	8.4	11.3
(2) 23	1.14	6.2	42.3	8.8	18.4	5.4	39.1	6.6	15.7	5.7	8.6	5.9	7.4
(3) 20	1.94	7.5	21.1	10.2	14.7	7.3	15.8	10.5	7.4	—	—	—	—
Means	1.51	*6.7*	35.0	*8.5*	16.9	*5.7*	22.5	*7.9*	10.1	*7.4*	9.6	*7.2*	9.4

Note : All values are *weighted means*, except final means for seasons.

Cropped Plot.—The nitrate-producing capacity of the topsoil of this plot is 33 p.p.m. which was surpassed only on 4 occasions during the dry spell in April and May, 1935. It was also nearly reached just after manuring. For the subsurface soil, the value is 24 p.p.m. and this was surpassed on 3 occasions mostly during the same dry period. Evidently in this plot the growing crop competes with the soil for nitrate, giving residual values numerically lower than those found in the fallow plot.

Pasture Plot.—Here the nitrate-producing capacity is 55 and 43 p.p.m. for top and subsurface soils, but neither value was reached during the period of the investigation, the highest figure recorded being 16 p.p.m. for topsoil and 18 p.p.m. for subsurface soil, implying rapid nitrate uptake by the pasture grass.

(3) *Relationship between rainfall, soil moisture and nitrate*

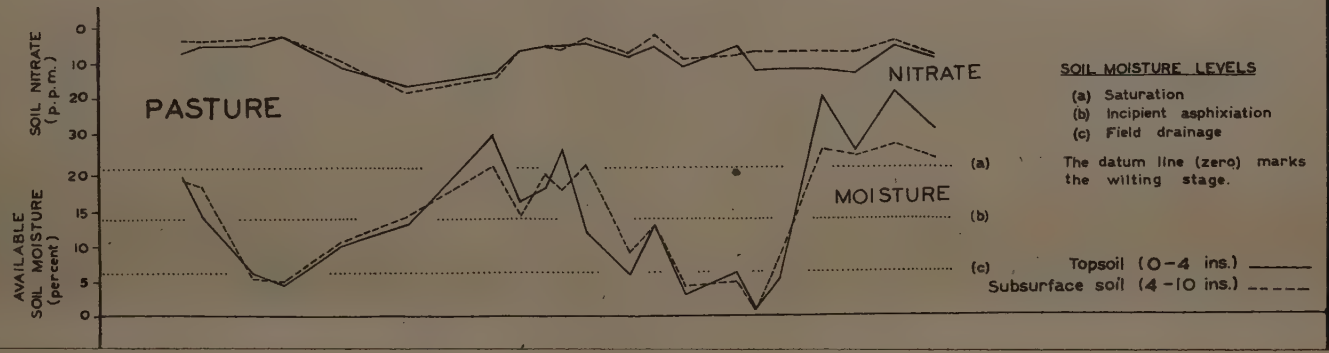
In general, the magnitudes and the range of values representing the fluctuations of soil moisture and nitrate support the contention that only a small fraction of the total rainfall is effective or necessary for maintaining satisfactory supplies of these agencies in a soil.

In the case of the soil under investigation, a residue of moisture and nitrate was lost by deep water penetration below the main rooting zone as soon as the rate of fall of rain regularly exceeded about 0.40 inches per hour. During dry intervals, and particularly when the dry season set in gradually, as in 1935, the moisture content of the soil slowly contracted within the non-capillary range, there being then little deep penetration, so that conditions eminently suitable for nitrate accumulation obtained. At the same time, the water-supply to the plant was abundant, so that rapid growth of the crop ensued. At a still later stage, the dry weather continuing, moisture contents reached the capillary range when it became increasingly difficult for the plant to obtain its requirements of water and nitrate. Accumulation of nitrate was then accelerated, the excess being stored in the soil until the next wet period. When the onset of the rains is sudden and intense, the store of nitrate that has accumulated in the soil may be lost before the growing crop can fully utilise it, but if the early showers are light, then nitrate may be held in reserve for the benefit of a succeeding crop.

(4) *Practical issues*

An important problem concerned in economic crop production in wet tropical regions where the rainfall displays marked wet and dry seasons (as illustrated by the experimental area under consideration) is how to utilise fully the natural supply of nitrate which accumulates during dry periods when soil conditions ensure an adequate degree of moistness and aeration without excessive leaching. Such conditions most generally occur toward the end of the dry season, so that, in order to take advantage of this nitrate accumulation, the crop must already be in the ground before the rains break, otherwise the accumulation may be lost. Where the land is under grass, however, (as in the pasture plot in this investigation) nitrate is absorbed as fast as it is produced and the risk of loss is reduced to a minimum. Thus by planting an area in fodder grass or converting it into a grass ley toward the end of the wet season, provided the crop survives the following dry weather, complete conservation of natural nitrate should be ensured. The absorbed nitrogen, fixed in the crop and in its

MOISTURE AND NITRATE FLUCTUATIONS IN SANDY SOIL AT I.C.T.A., TRINIDAD



humified residues, may be allowed to accumulate for several vegetative cycles and thus held in reserve until needed to nourish a crop grown for profit during a succeeding wet season.

Summary

1. The fluctuations in soil moisture and nitrate have been followed quantitatively in fallow, cropped and pasture land at the College Farm for a period of 33 months duration covering the greater part of three dry and three wet seasons. Topsoil (0-4 ins.) and subsurface soil (4-10 ins.) were considered separately.

2. The soil is a uniform fine sand with medium-high organic matter content and fairly high nitrifying capacity.

3. The daily rainfall has been arbitrarily analysed from continuous rain-gauge records into showers of intensity (*a*) over 0.75 ins. per hour, (*b*) 0.75-0.41 ins. per hour, and (*c*) 0.40 ins. per hour and below. The first category (20 per cent.) is assumed to comprise torrential rainfalls which run off the land and the last category (60 per cent.) light rainfalls which evaporate without penetrating; the medium rainfalls are thus assumed to provide the main source of soil water ("effective" rainfall) for plants growing within the experimental area, where they amount to only about 20 per cent. of the total rainfall in an average year.

4. Available soil moisture contents (gross soil moisture *minus* wilting coefficient) and nitrate-nitrogen contents have been determined approximately monthly. An attempt has been made to interpret the moisture data in terms of effective rainfall and of physical soil constants namely, saturation capacity, non-capillary pore-space, capillary pore-space (field capacity), physiological range and wilting coefficient.

5. Nitrate accumulation and utilisation have been followed in relation to soil moisture fluctuations. It was found that (*a*) considerable nitrate accumulation occurs when the available moisture content of the soil is reduced during the dry season to within the capillary range (*i.e.* below the $\frac{1}{3}$ index of texture value), (*b*) for moisture contents above this range but well below saturation capacity, nitrate may diffuse within the non-capillary pore-spaces, and (*c*) for moisture contents approaching the saturation capacity, deep percolation of water takes place and nitrate is leached downwards below the main rooting zone and so lost.

6. In order to utilise the accumulated store of soil nitrate (equivalent in this case to about 5½ cwt. sulphate of ammonia per acre 4 inches), crops should be established before the wet season fully sets in; this presents practical difficulties and involves risk. Forage grass crops and grass leys, planted before the soil has begun to dry out (preferably during the previous wet season), should fix most of this nitrate and so conserve it for the use of succeeding cash crops.

Explanation of the Diagram

The main results obtained in this investigation are displayed in the accompanying diagram.

(1) *Total rainfall*: This is represented at the bottom of the diagram by vertical columns at 6-day intervals.

(*a*) The unshaded top part of each column gives *run-off*, arbitrarily estimated as "torrential" showers of intensity over 0.75 ins. per hour.

(*b*) The cross-hatched part gives *evaporated* water, estimated as "light" showers of between 0.75 and 0.40 ins. per hour.

(*c*) The blackened part gives *penetrating* water partly stored within the rooting zone, estimated as "medium" showers of intensity below 0.41 ins. per hour.

(2) *Soil moisture*: Data for available soil moisture (expressed as weight per cent.) determined by direct weighing on topsoil and subsurface soil samples and subtracting the value for wilting coefficient, are shown for fallow, cropped (maize) and pasture land. The three horizontal dotted lines across each soil moisture graph indicate (*a*) the saturation capacity, (*b*) the upper limit of physiologically-available water and (*c*) the field capacity (capillary pore-space). The datum line (zero) indicates the wilting point.

(3) *Nitrate*: Data for nitrate-nitrogen contents of the periodic soil samples (expressed as parts per million by weight) are shown for comparison with available soil moisture.

(*a*) As the soil dries out into the capillary range (values for available soil moisture below about 6 per cent.) nitrate tends to accumulate.

(*b*) As the soil is wetted above field capacity (values above 6 per cent.), diffusion of nitrate within the non-capillary pores may occur.

(*c*) As the soil is wetted further, up to the saturation capacity (values approaching 21 per cent.), downward deep percolation (free drainage) ensues, accompanied by rapid leaching and loss of nitrate.

NOTICE TO SUBSCRIBERS

THE late appearance of this issue of *Tropical Agriculture* is much regretted. It is due to circumstances, however, quite beyond the control of the College Publications Department, the delay being due to exceptional pressure of work at the Government Press, Port-of-Spain, where the Journal is printed. Everything is being done to get back on the regular publication schedule but it is feared that it will be some time yet before conditions will be normal again. Readers are accordingly notified that the April, May and June issues are all likely to be unavoidably delayed.

* * *

The Editor is prepared to consider signed articles for publication in *Tropical Agriculture*. Such articles should normally vary between 1,000 to 6,000 words and may be illustrated if desired.

THE UNKNOWN DISEASE OF THE COCONUT PALM IN JAMAICA *

BY

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Introduction

Martyn (1945) has recently published a comprehensive review of coconut diseases in Jamaica including one considered by Briton-Jones (1940) and Bain (1940) to be the same as the bronze leaf wilt of coconuts in Trinidad, which is claimed to be caused by "conditions favouring a deficiency in the water supply of the palm in dry periods" and to "water logging leading to root destruction". Martyn stated that the immediate result of Bain's diagnosis in Jamacia was that the cutting down and burning of diseased palms hitherto generally carried out was largely abandoned. The anxious growers began to question the advisability of this change in policy when the disease appeared to be on the increase and especially when palms were killed by it at Flint River (Plate 4) on a soil which was claimed to be unconducive to the incidence of bronze leaf wilt. Following certain of his own investigations, Martyn stated that the disease in Jamaica was probably the same as that in Trinidad but doubted the theory of a non-parasitic wilt and considered that, until an explanation of the disease was found, it should be regarded as infectious and growers should continue to cut and burn their diseased palms.

The author has recently carried out further investigations in Jamaica and after making a detailed study of the development of symptoms on individual palms throughout the year, he is of the opinion that Martyn was fully justified in maintaining that Bain's hypothesis could no longer be accepted as an explanation for the behaviour of the disease in Jamaica. Little progress seemed likely towards the elucidation of this disease until the growth of healthy and diseased plants was studied throughout the year in order to note any features which might indicate the cause of the disease. The results of this work are presented in this paper.

From a consideration of the data obtained, it was considered that the greatest hope of discovering the cause of the disease lay in a piece of co-operative research between a plant pathologist and physiologist, working with young seedlings on soils where they can now be expected to become diseased under two years old, *i.e.*, when they are small enough to be handled with far greater ease than older plants. It was thought that facilities for such combined research would probably be most readily provided in Trinidad and it was decided that the author should examine the suitability of such a project by visiting that island and satisfying himself that the symptoms of bronze leaf wilt in Trinidad were exactly similar to those of the disease in Jamaica.

As a result of a visit made to Trinidad and British Guiana at the end of September, 1945, there is no doubt that the disease in Jamaica is *definitely not* the same disease as bronze leaf wilt and also that it is not present in the other two countries mentioned above.

Until the cause of the disease in Jamaica is diagnosed, it is best to refer to it simply as the unknown disease of coconuts in the Caribbean area. The salient differences between the symptoms of the unknown disease and those of bronze leaf wilt are noted in this paper. Although the drought hypothesis is claimed to explain the incidence of bronze leaf wilt in Trinidad, there is no relationship between drought and the incidence of the unknown disease; on the contrary palms are definitely more susceptible when they are growing actively.

Although the behaviour of affected palms is suggestive of an infectious disease, the author is inclined to think that the nutrient status of the palms is the primary factor affecting the incidence of this disease which appears to be confined to the western and north western Caribbean area where it is, also, localised within the islands themselves. There is, therefore, a possibility that some deficiency or even a toxicity may occur in the soil throughout the affected areas. If the disease is infectious it would appear to be either soil borne, or else soil conditions greatly affect the palms' powers of resistance.

Symptoms of Disease

(*a*) BEARING PALMS

The first sign of the disease is the premature falling of a few nuts from an apparently healthy palm, before or at the time that one of the spathes opens showing an inflorescence which may have just the ends of a few branches (rachides) discoloured brown. There is no general rule regarding the size of the nuts which fall first. It is only occasionally that a spathe opens diseased before the nuts start falling. As the disease continues to develop, each inflorescence tends to be more severely affected than the one which opened before it. Discoloration of the branches occurs in the young inflorescence generally before the spathes split open. The branches of the earlier diseased inflorescences become increasingly withered. As the diseased spathes open prematurely, four or five may open with shrivelled inflorescences during the time that only two or three would normally open on a healthy palm.

The disease tends to affect one side of a palm more than another at first; this unilateral effect may be so marked that a palm may appear healthy when seen from one side although nearly every

* Known locally as West-end Bud Rot.

(A) Rate of Developm—
(B) Rate of Leaf Grov
A. Av. increase in len

Position of first Disease Spathe = North-East (N.E.)

Bunch No.	Position of bunch in crown	Av. Nut size		Dec.	
		Length	Circumf.	19	29
1	NE	9″	15″	1.1	1.2
				1.3	1.3
				1.3	1.4
				1.3	1.4
2	N	12½	21	1.0	0.9
				1.0	0.8
				1.1	0.8
3	E	4	6½	1.3	1.4
				1.2	1.3
				1.1	1.3
4	S	7½	12	1.4	1.5
				1.4	1.6
				1.4	1.4
5	NW	5¾	8½	1.4	1.3
				1.1	1.3
				1.1	1.3
				1.2	1.3
6	W	11½	18½	1.4	1.2
7	SW	4	6½		
				1.6	1.8

Table 1

ent and Fall of Nuts on a Diseased Palm

gth on same Diseased Palm

T]gth of nut per day (millimeters) and date on which nuts fell (F)

	January				February				March				April				May		
3	9	16	23	30	6	12	20	27	6	13	20	26	4	10	17	23	1	11	22
1.0	1.0	0.0	F																
Ma 1.0	1.3	0.3	F																
comp																			
Jama 0.8	F																		
(1940																			
bronz 1.1	0.6	F																	
claim																			
a def 0.9	0.7	0.5	0.4	0.2	F														
dry l																			
root 0.8	0.3	0.3	F																
imme																			
was t 0.9	0.2	0.2	F																
palms																			
aband																			
quest 1.7	1.3	1.3	F																
when																			
and 1.2	0.8	0.3	F																
Flint																			
1.2	0.2	1.1	1.1	1.1	F														
to be																			
wilt.																			
Mart 1.5	1.3	1.2	1.4	1.0	F														
prob																			
the t 1.4	1.5	1.4	1.5	1.4	0.6	0.4	F												
that,																			
found 1.3	1.5	1.1	0.3	F															
grow																			
disea																			
Th 1.4	1.2	1.1	1.0	0.4	F														
inves 1.2	1.2	1.1	1.1	1.4	0.4	F													
detai																			
indiv 1.3	1.0	1.1	1.2	1.4	F														
opini																			
tainii 1.2	1.1	1.1	1.1	1.4	F														
be ac																			
the c																			
likely 1.1	1.0	0.9	0.9	0.9	0.9	0.7	0.7	0.7	0.7	0.9	0.1	0.3	0.0	0.0	F				
the g																			
studi				1.4	1.4	1.4	1.4	1.6	1.7	1.7	1.7	1.8	1.7	F					
featu																			
disea				1.3	1.4	1.4	1.4	1.4	1.7	1.7	1.7	1.7	1.7	F					
this p																			
Fr				1.4	1.4	1.3	1.3	1.5	1.7	1.7	1.7	1.9	0.8	F					
was																			
disco				1.3	1.4	1.3	1.1	1.4	1.6	1.7	1.7	1.7	1.7	F					
of																			
path				1.1	1.3	1.3	1.2	1.3	1.6	1.6	1.6	1.6	1.2	F					
seedli																			
to b				1.1	1.3	1.2	1.2	1.4	1.6	1.5	1.3	1.6	1.6	1.2	0.6	F			
when																			
far gr																			
that	Maximum Leaf Growth per Day (Inches)																		
prob 1.5	1.5	1.6	1.4	1.5	1.6	1.7	1.6	1.7	1.6	1.8	1.6	1.7	1.6	1.6	1.6	1.6	1.5	1.1	cut
and i																			
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of b																			
simil																			

nut has fallen and spathes have opened diseased on the other (Plates 1 and 2). After one or two spathes have opened diseased, another may open quite healthy in the unaffected section of the crown. When this observation was first made such cases were mistaken for signs of recovery, but subsequently the disease spreads throughout the crown. A typical example of the distribution in the nutfall on one palm is given in Table 1, which shows that the nuts fell over a period extending from January 9th to April 17th, after the first spathe had opened in the north east (N.E.) section of the crown, the first nuts to fall were situated nearby, while the last nuts to fall were on the opposite side, namely, in the south west (S.W.) sector.

The length of time taken for palms to shed all their nuts varies from one to four months, in old palms the average is approximately two. The unilateral effect is more inclined to be marked when the nuts fall slowly.

Diseased palms seldom show any sign of discoloration in their leaves until all the nuts have fallen; once the lower leaves start to bronze, the remainder usually follow in quick succession, the whole crown being affected within a month. The foliage seldom shows even the slightest sign of unilateral bronzing, although very rarely the tip of a middle aged leaf turns bronze-yellow in one sector of a palm which before long becomes diseased. The old leaves are not shed quickly and remain in their normal position until they fall suddenly without hanging clustered around the stem.

The immature shell of the affected nuts becomes blackened in irregular patches usually first nearest to the calyx. This necrosis is not always seen in nuts cut off an affected bunch but always develops rapidly after they fall. There is no discoloration in any of the tissues between the discoloured shell and the abscission scar at the base of the nut. Exactly the same discoloration occurs in nuts which occasionally fall prematurely from healthy trees due to the stalk of a bunch being bent by the weight of its own nuts or by someone harvesting nuts.

The first diseased spathe may be of normal proportions, in which case the male flowers are normal in size and colour to those of a healthy inflorescence—the only sign of disease being the blackened tips of the branches from which these flowers soon fall. Frequently the first spathe to open is itself affected unilaterally, as shown in Plate 5 where some branches have died back, while others appear unaffected. In the latter, the male flowers may be much lighter in colour on one branch than another, in which case they tend to be much smaller towards the ends of the branch than at the base, as shown in Table 2, where the average size of individual male flowers is tabulated, for every inch and a half along the length of one rachis, in a healthy and a diseased inflorescence.

The differences in the size of flowers are due to a difference in their stage of development, the smaller flowers being more immature than the larger ones.

No difference whatever has been noted between the general development of healthy and newly diseased palms in respect of such factors as (*a*) the

Table 2

Size of male flowers on one rachis showing no signs of discoloration (millimeters)

Position on rachis	Base	2	3	4	5	6	7	Top
Healthy: Length	10.1	10.1	9.9	9.1	9.3	10.0	9.0	9.8
Breadth	4.8	4.6	4.6	4.7	4.5	4.4	4.5	4.6
Diseased: Length	10.8	10.0	10.1	9.2	8.6	8.8	7.6	6.9
Breadth	4.4	4.6	4.4	4.5	3.5	3.7	3.5	3.5

Table 3

Size of male flowers on different rachides of one diseased spathe (millimeters)

	No. of rachis						
	1	2	3	4	5	6	7
Length of rachis (in)	10.5	8.7	8.0	9.0	10.8	12.0	14.0
Length of tip die-back (in)	4.4	3.5	4.0	4.2	3.7	0.0	0.0
Av. length: Tip	6.6	4.8	5.3	5.3	5.4	3.9	4.0
(mm) Base	6.4	5.7	5.5	6.6	6.5	7.5	7.0
Av. breadth: Tip	3.6	3.1	2.8	2.9	3.2	2.4	2.6
(mm) Base	4.2	3.8	2.5	3.6	3.5	3.5	3.7

number of exposed or unexposed leaves present (*b*) the size of lamina (*c*) length of petiole and (*d*) nut size.

Comparison between symptoms of	
Jamaica	*Trinidad*
Unknown disease	*Bronze leaf wilt*
1. Usually no discoloration of foliage throughout period of nutfall.	Definite bronzing and yellowing of several leaves before nuts fall.
2. Nuts of any size start to fall first.	Youngest nuts fall first.
3. Nuts fall on one side of palm more than another at first.	No unilateral effect.
4. No nuts on palm when bronzing is pronounced.	Many nuts may still be on palm even when severely bronzed.
5. Inflorescences open discoloured at start of disease.	Inflorescences may remain healthy until bronzing is well advanced.
6. Up to five spathes may dry up before heart is killed.	Spathes affected suddenly so that only two or three may dry up before heart is killed.
7. Bronzed leaves remain at normal angle when dry; later break off without hanging down stem.	Bronzed leaves hang down and remain clustered close around stem after drying.

Note: Johnston (1912) claimed that a bud-rot of coconuts in Jamaica was the same as that in Cuba. Unfortunately his description of the disease was not very explicit and, as Martyn suggested, he may have been confusing bud-rot with bronze leaf wilt. It seems more than probable, however, that he was referring to the unknown disease now under investigation in Jamaica.

(*b*) Non-Bearing Plants

Without taking measurements of leaf growth the only way that the disease can be identified for certain on young plants is by examining the youngest heart leaves. In Jamaica if bronzing is accompanied by dieback of the heart leaf, then the trouble may be safely attributed to this unknown disease, owing to the absence of red ring disease—bronzing alone being no criterion for diagnosis.

When a coconut palm is affected by drought the pinnae of the leaves fold up and this is first noticeable in the youngest leaves indicating a shortage of water nearer to the growing point than elsewhere in the crown. It is significant, therefore, that in the disease (*a*) there is no sign of the pinnae folding abnormally when the first symptoms are evident (*b*) as shown later, there is no slowing down of growth in the young leaves at that time and (*c*) the oldest leaves are the first ones to show any discoloration in the foliage.

Effect of Disease on Root System

No organism has been isolated which could be considered a parasite likely to cause the disease. Observations made after a prolonged drought showed that diseased trees which had even reached the stage when all nuts had fallen are still capable of active growth in their surface feeder roots. Of the thicker roots the number of lighter coloured (younger) ones is the same in recently diseased trees as it is in healthy ones, thereby indicating that root development is apparently normal up to the time that the palms become diseased. In the last stages of the disease there is no sign of activity in the root system. Examination of the rootlets of such palms did not yield any more promising results than those recorded for bronze leaf wilt.

In very young palms (18 months old) found dying of this unknown disease, there has been evidence of rotting at the base of the young stem resulting from infection through the roots even before the haustorium had completed digesting the "meat" in the nut. A fungus, *Rhizoctonia* sp. (? *solani*), was recently isolated from the junction between such healthy and diseased tissues. When inoculated into the base of the young plants, the hyphae readily entered the tissues, but were soon confined to a zone round the area of inoculation.

Growth Rate of Diseased Palms

These investigations could not have been carried out under more favourable conditions for studying the effect of rainfall on the incidence of this disease because an extremely severe drought was experienced early in 1945, both in the districts where the disease is present as well as those nearby where it has never been recorded. The growth rate of the palms was recorded, as far as possible, every two weeks throughout the year. The method of measuring leaf growth was similar to that described by Copeland (1931). The increase in length of the fastest growing leaf between each record was taken as the maximum rate of leaf growth for each individual plant, the average for a plot being calculated in terms of growth in inches per day between the dates of recording.

As the growth in the length of nut is basipetal the measurement of nut growth was made by marking the nut around the edge of the calyx, preferably with a wax pencil, then measuring the distance between successive markings so that the increase per day could be calculated in millimeters. All growth in length of the coconut occurs underneath the calyx, because the distance between any two marks made along the surface of a nut remains unchanged throughout the development of that nut. The girth of the nut is, of course, always increasing. The increase in girth of nut was calculated from measurements of the maximum circumference; the method, however, is not as accurate as that used for estimating growth in length. The latter represents the amount of new tissue developed, whereas the increase in circumference represents the rate of maturity of existing tissues.

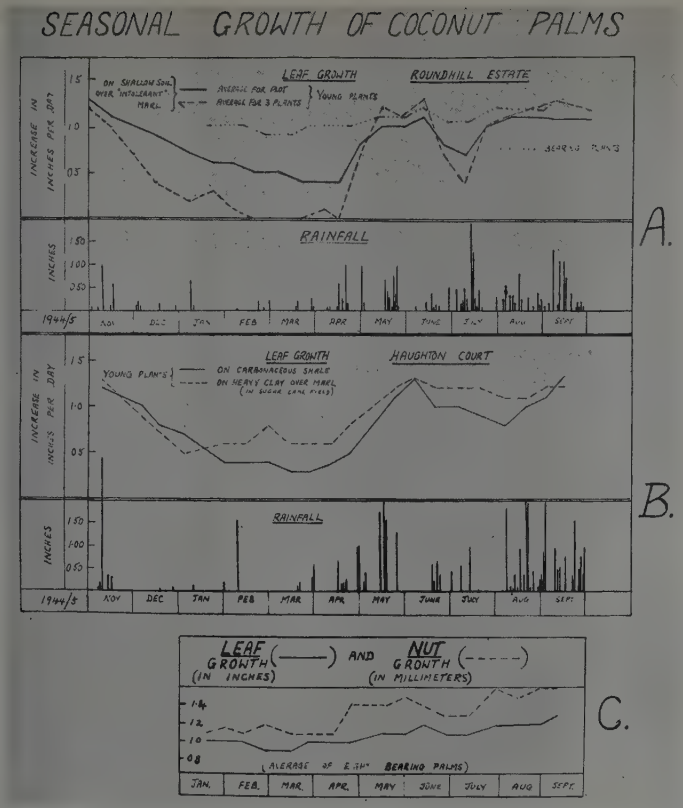

SEASONAL GROWTH OF COCONUT PALMS
LEAF GROWTH
ROUNDHILL ESTATE
ON SHALLOW SOIL OVER "INTOLERANT" MARL
AVERAGE FOR 3 PLOTS
AVERAGE FOR 3 PLOTS
YOUNG PLANTS
INCREASE IN INCHES PER DAY
1·5
1·0
0·5
RAINFALL
INCHES
1·50
1·00
0·50
1944/5
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
A.
LEAF GROWTH
HAUGHTON COURT
YOUNG PLANTS
ON CARBONACEOUS SHALE
ON HEAVY CLAY OVER MARL
(NO SURFACE DRAINAGE)
B.
LEAF GROWTH (——) AND NUT GROWTH (- - - - -)
(IN INCHES)
(IN MILLIMETERS)
1·4
1·2
1·0
0·8
(AVERAGE OF EIGHT BEARING PALMS)
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG
SEPT.
C.

FIG. 1.

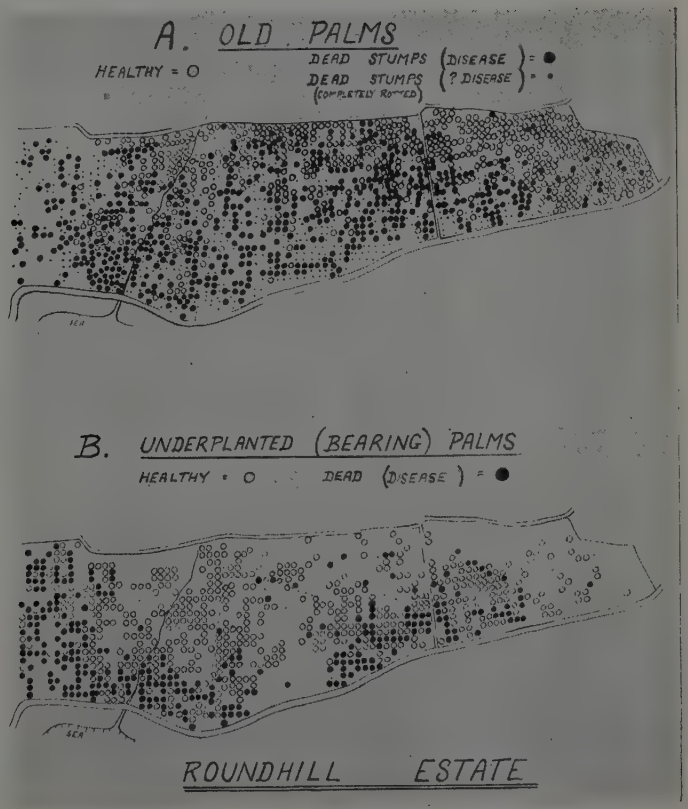
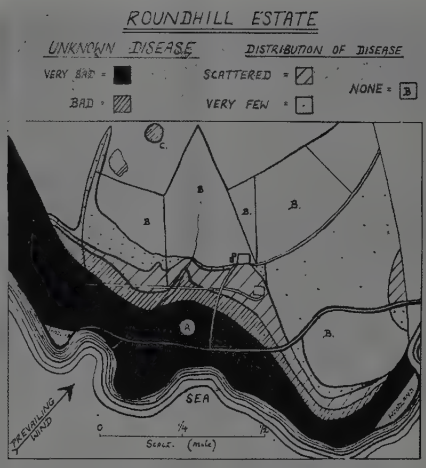

A. OLD PALMS
HEALTHY = O
DEAD STUMPS (DISEASE) = ●
DEAD STUMPS (? DISEASE) = •
(COMPLETELY ROTTED)
SEA
B. UNDERPLANTED (BEARING) PALMS
HEALTHY = O
DEAD (DISEASE) = ●
SEA
ROUNDHILL ESTATE

FIG. 2.


ROUNDHILL ESTATE
UNKNOWN DISEASE
DISTRIBUTION OF DISEASE
VERY BAD =
BAD =
SCATTERED =
VERY FEW =
NONE =
B
C
A
SEA
PLEASURE GROUND
PLEASURE GROUND
0
1/4
1/2
Scale. (mile)

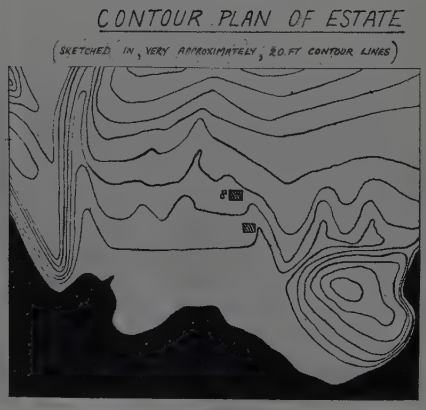

CONTOUR PLAN OF ESTATE
(SKETCHED IN, VERY APPROXIMATELY, 20 FT CONTOUR LINES)

FIG. 3.

PLATE 1.—Early stage of disease. Foliage healthy. Nearly every nut fallen on one side of palm.

PLATE 2.—Side of palm opposite to that shown on Plate 1 (Photographed on same day). Nuts not started to fall.

PLATE 3.—Palms of this type, blown down in previous hurricane, are the only ones surviving in a completely devastated coconut plantation.

PLATE 5. — Inflorescence removed from unopened spathe, showing unilateral distribution of discoloured rachides (some discoloured in middle but not at tips). Most of the male flowers fallen off.

PLATE 4. — Palms killed by the disease at Flint River on free draining soil with a texture very suitable for the vigorous development of coconut palms.

The rate of growth of the inflorescence was measured by recording the increase in length of the unopened spathes in relation to a basic mark made on the petiole of the subtending leaf, while the increase in girth was calculated from measurements made at six-inch intervals from the tip downwards.

Measurements of leaf, nut and inflorescence growth on bearing trees take some considerable time so that only a few trees could have complete records taken on them. As all but the smallest and largest nuts grow usually at a similar rate on any one palm, the rate of nut growth was estimated on a number of palms by measuring nuts on only two bunches; if by any chance there was a difference, the quicker growing bunch on each plant was taken in obtaining an average for all the trees.

Fortunately the disease affects non-bearing palms throughout the diseased areas in Jamaica and, as these are comparatively easily recorded and red ring disease is absent, several different plots of these younger plants were chosen for measurements and observation throughout the investigations. Unfortunately, the incidence of disease in these plots was far smaller than in those of bearing palms.

As a result of these extensive records the following features of the disease have been established :—

(*a*) Bearing Plants

Table 1 shows the rate of growth of nuts and leaves of a diseased palm on which measurements were made at weekly intervals, the data being calculated as incremental increases per day. The leaf growth was measured in inches and the nut growth in millimeters.

(i) Leaf growth may remain normal even until a month after the last nut falls. Observations have shown that leaf growth starts to decline at the time the lower leaves start to bronze noticeably. Stripping off all the nuts, when the first ones start falling, does not affect the time taken for leaf growth to begin slowing up (*see* Table 4, Palm 6).

Table 4

Time taken for leaf growth to be affected in bearing palms

Palm No.	Date disease first recorded	Date leaf growth started to decline	Approx. time between start of disease and slowing of leaf growth
1	20/11/44	6/3/45	3½ months
2	21/11/44	1/5/45	5½ months
3	19/12/44	1/5/45	4½ months
4	26/ 3/45	22/6/45	3 months
5	21/ 5/45	21/8/45	3 months
		All (123) nuts removed when palm first seen to be diseased	
6	26/ 4/45	18/7/45	3 months

(ii) Once a nut is affected, its rate of growth declines rapidly and the nut usually falls within two weeks. Nuts develop normally on many bunches while they are falling from other bunches. When some nuts are falling on a bunch, others on the same bunch may still be growing normally.

(iii) The seasonal variation in the rate of nut growth is more marked than that of leaf growth. This is shown in Fig. 1 C where a comparative graph is made between the relative growth rates of leaves and nuts on eight different bearing palms at Round Hill. Very soon after rains fell in April, at the end of a sustained drought, nut growth increased rapidly, fell gradually during a short period of drought in June and then rose again rapidly when rains fell again in July. Leaf growth on the other hand reacted comparatively slightly in the same periods. Reference is made later to the possible significance of this observation.

(iv) Diseased spathes increase in length at a normal rate during the period when the growth of the leaves is unaffected, but the decrease in girth is marked from the time that the first spathes open diseased. The diseased spathes open prematurely, so that four diseased spathes may open in the same time that two healthy spathes would normally open.

(*b*) Non-bearing Plants

The leaf growth of young diseased plants is affected very suddenly (*see* Table 5), being so marked that the initial stages of the disease can be more accurately estimated by recording the rate of their growth than by noting any change in the colour of the foliage, because bronzing of the foliage may not occur until leaf growth has almost ceased. The heart leaf usually starts to show signs of dieback within two weeks after the leaf growth has stopped.

In non-bearing plants the initial growth rate of diseased plants is generally as fast as that of healthy plants of similar size in the same plantation.

Note.—Although this sudden effect of the disease is characteristic, two out of forty young palms died slowly over a period of about three months. It is possible that such plants did not die of the disease in question.

Seasonal Incidence of Disease

The incidence of disease in all observation plots was recorded throughout the year. In the case of bearing palms, plants were first recorded as being diseased when there was evidence of premature nutfall shortly followed by the opening of a diseased inflorescence. The only accurate means of recording the date on which the disease first affects non-bearing plants is by noting the time that growth rate declines abnormally fast. These two criteria have, therefore, been used to estimate the influence of rainfall on the incidence of the disease during these investigations (reference Table 6 and rainfall figures in Fig. 1).

Table 5

Leaf growth rate of diseased (non-bearing) palms

	A—Diseased				Date when (O) recorded	B—Healthy			
	Prior to disease	No. weeks after first affected				No. weeks (Similar dates to A)			
	0	2	4	6		0	2	4	6
1	1.7	1.2	0.4	0.0	31/10/44	1.6	1.4	1.3	1.1
2	1.4	0.8	0.3	0.2	1/12/44	1.4	1.2	1.0	0.9
3	1.1	0.7	0.5	0.2	21/12/44	1.1	1.0	0.8	0.9
4	0.9	0.6	0.3	0.1	17/ 2/45	0.9	0.9	0.9	0.9
5	1.0	0.7	0.1	0.0	10/ 5/45	1.0	1.2	1.3	1.2
6	1.0	0.7	0.3	0.0	7/ 6/45	1.1	1.0	1.0	1.0
7	0.3	0.1	0.0	0.0	16/ 6/45	0.4	0.3	0.3	0.3
8	1.0	0.7	0.3	0.0	21/ 6/45	1.0	1.1	1.0	1.0
9	1.1	0.5	0.1	0.0	5/ 7/45	1.1	1.0	1.0	0.9
10	0.9	0.6	0.4	0.0	5/ 7/45	0.9	0.8	0.9	0.9
	1.0	0.7	0.3	0.1	Mean	1.0	1.0	1.0	0.9

Table 6

Seasonal incidence of disease

A—Bearing Palms

	Total Healthy Dec.	% Newly diseased each month * 1945									Total % diseased in 9 months
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
a	116	1	2	1	6	4	0	2	5	16	31
b	203	12	14	1	2	4	5	22	23	14	66
c	255	4	6	4	2	3	2	2	3	4	27

* Method of estimating %

Example—No. healthy June 1st = 100 No. diseased in June = 20% = 20.0
Remainder healthy July 1st = 80 No. diseased in July = 20% = 25.0
Remainder healthy August 1st = 60 No. diseased in August = 20% = 33.3

(*a*) Round Hill (*b*) Haughton Court (*c*) Tryall

B—Non-Bearing (Young) Palms

(Leaf growth records)

	Total Healthy Oct.	No. plants newly diseased each month											Total % diseased in 11 months
		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
d	63	6	5	1	0	0	0	1	0	0	1	1	24
e	60	1	0	0	0	0	0	1	1	2	1	1	11
f	16	2	1	0	1	1	1	0	0	0	0	0	38

(*d*) Round Hill (shallow soil overlying marl—hillside)
(*e*) Haughton Court (heavy clay overlying marl—flat)
(*f*) Spring Garden (black clay loam overlying heavy yellow clay—flat)

Note.—Other leaf growth recording plots not sufficiently diseased to be tabulated.

One noticeable feature is the very few new cases of disease recorded in March, at the height of the drought. This is exactly opposite to the behaviour of bronze leaf wilt in Trinidad. Apart, therefore, from the marked difference between the earliest symptoms of the two diseases, this opposite seasonal effect supplies additional evidence to show that there is little likelihood of the diseases being inter-related in any way.

General observations were made on a group of diseased plants at Round Hill (Table 6-Aa) at the start of these investigations in October, 1944, but when the records of seasonal incidence were started, there were only very few cases in that area. As soon as rains fell in April there was a sudden increase of the disease, this being followed by only a few new cases in June and July, an increase again in August and a big increase in September. In this part of Round Hill, therefore, the disease coincided fairly closely with periods of sudden rises in growth rate exhibited by the nuts in these bearing palms (*see* Fig. 1 C), namely, at the end of April and at the end of July.

At Haughton Court (Table 6-Ab) on the other hand there was no response to the first rains but a remarkable increase occurred suddenly in July, being maintained for the next two months. At Tryall (Table 6-Ac), in a plantation which was completely destroyed by the disease on its western boundary, there was little variation in the intensity of the disease from month to month, although it fell a little in the drier months, starting to rise again in September.

It is of interest to try and interpret the behaviour of the disease on these three different estates in relation to their three different types of soils.

	Round Hill	*Haughton Court*	*Tryall*
Aspect	Flat close to sea	Steep, hilly 1 mile from sea	Flat close to sea
Top soil	Deep, friable	Shallow, heavy clay	Shallow, black clay loam
Subsoil	Gravelly, heavy loam	Fissured, inclined shale	Heavy yellow clay
Drainage	Free	Free	Poor

At Round Hill the rainfall in April/May would have been all absorbed and would have drained through the soil freely. The well developed root systems would have absorbed the water readily with the result that, following the sudden initial increase in growth rate of nuts, the palms were probably affected by the short but rather severe spell of drought in June; their reaction to the rain in July was reflected in the second rapid increase in nut growth at the end of that month. At Haughton Court, however, there is a considerable matting of roots in the shallow, heavy, surface soil and the roots penetrate only into the fissures of the shale below, where they travel to a considerable depth. It is doubtful whether the April/May rains were freely absorbed in these soils on the hillsides, under pasture, as they remained hard and did not crack nearly as extensively as where the younger palms were growing. Unfortunately, the bearing palms at Haughton Court, like those at Tryall, were all too high to allow for growth measurements being taken. It is probable, however, that the April/May rains were insufficient to stimulate growth as actively there as at Round Hill until they were augmented by the subsequent July and August rains. The disease did not start to increase until that time, when it did so in a remarkably rapid manner.

At Tryall the heavy nature of the soil again probably prevented absorption of the rain to any depth. It was noticeable that the pasture did not grow much until after the end of July and then it was so luxuriant that it may well have been competing seriously with the coconut roots so that growth of the palms may have been affected by the drought until late in the growing season. It is significant that there was a severe drought also in 1944, and the disease was prolonged into January and February, 1945, on the heavier soils of Haughton Court and Tryall, whereas on the lighter and freer draining soils at Round Hill there was very little disease to be seen in those months.

The amount of disease on the non-bearing palms is considerably less than on the bearing palms, as the records show in Table 6-B. Very few plants were newly affected during the drought and it appears as if these plants become most susceptible towards the end of the wet season. The three young, 18-month old seedlings which succumbed to the disease, did so in the month of August at Haughton Court when moisture conditions were very favourable for growth and the soil had been well cultivated.

It was surprising to note the very rapid response in the activity of palm growth immediately following a fall of rain which was sufficient to penetrate only a few inches into the soil after a prolonged drought. This showed that the surface roots of palms can withstand excessive drought without being killed, in other words that such roots are capable of remaining dormant through such weather, being quickly activated when moisture conditions become favourable for growth. The following two observations have supplied proof of this property of the coconut root.

Following the severe drought in the early months of 1945, the surface feeder roots of bearing trees were dug up a week after the onset of rains, active white root ends were clearly visible in the fine feeder roots within the top three inches of soil. The ability of the coconut root to withstand drought was, however, more forcibly demonstrated by three young non-bearing plants, the roots of which were practically confined to growth in six inches of a dark, friable top soil overlying a type of marl into which their roots failed to penetrate. These palms were, therefore, particularly liable to drought injury. Reference to Fig. 1A shows

that these three palms practically stopped growth altogether from February 5th until April 16th as a result of the total rainfall being only 4.77 inches between November 1st and April 16th. When 4.08 inches of rain fell between April 16th and 30th the plants responded so quickly that their rate of growth increased to 0.7 inches per day by April 30th and then reached the surprisingly high rate of 1.2 inches per day within the next two weeks. This was even faster than the average for all the recorded plants which were mostly large plants. No doubt the excessive growth was stimulated by the reserves accumulated when the plants were inactive. These very shallow rooted plants must, nevertheless, have been quickly activated and can have suffered little, if any injury, during the prolonged drought. Up to September these three palms showed no sign of any bronzing in their foliage—a feature which might have been expected if Summers' (1922) hypothesis could be applied to the coconut palm, as suggested by Bain to explain the development of bronze leaf wilt in the wet season "due to the action of oxidising enzymes upon the chromogens produced during the drying of the leaves". It seems very doubtful, therefore, that this class of soil enduces the disease through its inability to provide adequate moisture to the palms.

From a consideration of all the above data this unknown disease appears to be favoured by seasonal conditions which promote active growth, rather than by simply encouraging a physiological dieback of the roots enduced by drought or waterlogging.

Soil Condition affecting Incidence of Disease

Observations in the Bahamas as well as in Jamaica support the view that soil conditions play an important part in controlling the incidence of the disease. Just as in the case of bronze leaf wilt, the more luxuriantly the palms grow and the better yielding capacity they have, the more susceptible they appear to be to the disease.

Even though the disease has devastated plantations on very different types of soil, it tends to spread at a uniform rate throughout any area where the soil is uniform, whereas in fields consisting of different soil types the rate of spread tends to differ on each soil. This is very noticeable at Round Hill and Tryall estates, which are the only plantations of any size remaining along the Hanover coast line. It is especially interesting to note that the disease at Round Hill is killing the young under-planted and now bearing palms most rapidly in the very same areas that the old trees have been most severely attacked since 1934 (Fig. 2) and yet, on the other hand, the disease has never affected the old palms in the centre of the estate (Fig. 3B) which are growing only a quarter of a mile away and which, incidentally, are straight downwind from this heavily infected area.

There is one small but well defined patch of the disease (Fig. 3C) where other young bearing palms have only succumbed to the disease slowly during the past four or five years and where there has not been a single new case of the disease in the past year. In fact it appears as if the palms have now acquired a degree of resistance to the disease after passing through a period of susceptibility. This is quite unlike the under-planted plants, previously mentioned, which are still dying out rapidly.

At Tryall the disease was at first extremely active on the western boundary where hardly a single tree now remains standing; it has been serious more recently on its eastern boundary and also close to the sea along the shore connecting the other two areas. On the other hand, palms of similar age have been free of the disease between and inland from the affected areas although being directly downwind from the latter.

The rate of spread of the disease up to valleys from diseased areas on the coast also varies considerably. At Flint river, adjoining the eastern boundary of Tryall, the disease has destroyed nearly all the coconuts at the mouth of the river (*see* Plate 4) which flows down through a limestone valley where the palms are quite free of the disease to within a quarter of a mile of the devastated area which is situated directly upwind. On the other hand, further along the coast near Lucea, the disease has penetrated inland to a depth of 2 or 3 miles up a valley in which the soil is mostly carbonaceous shale (perhaps the most susceptible type of soil along the coast).

On New Providence island in the Bahamas the disease is only present on the fairly deep, brown sandy soils (windborne, oolitic limestone). It appears to have been present for the last 20 years on the golf course just outside Nassau, whereas the many old palms growing in the gardens of Nassau are quite free of the disease, as also are those growing on the extensive areas of flat limestone rock which comprises most of the island's surface. At Lyford Cay the palms grow vigorously and are affected at all ages from three years old upwards so there can be no question of the roots of the smaller palms being subjected to any water-logging by the water table which lies 5 or 6 feet below the surface in these sands.

The biggest plantations in the Bahamas are on the neighbouring islands of Andros and Eleuthera where, strangely enough, the coconuts are free of the disease although growing on the "white sands" which only differ from those of New Providence in containing practically no humus. This unknown disease would appear, therefore, to be encouraged by the soils which favour the best growth in these islands also.

Reviewing the incidence of the disease, it is evident that certain soil conditions definitely seem to affect the spread of the disease and in the author's opinion this may be due more to the different nutrient status of the plants growing on the various soils rather than to the effect of the soil on the development of any virulent parasite (*see* Postscript).

Discussion

Is this unknown disease of coconuts infectious or not? That is the first problem to be solved. There is so much conflicting evidence connected with the problem, for instance :—

If any organism is associated with the disease it must be very virulent to have destroyed whole plantations of coconuts in Jamaica within the space of three or four years and to have been capable of doing this during the past forty years, first in Westmoreland and more lately in Hanover. Yet it has never spread eastwards and is still confined almost entirely to the coastal regions in the affected areas. Similar cases of the inability of this disease to spread over a short distance have also been noted in the Bahamas.

In spite of the popular belief that the disease has been windborne in Hanover, there has been no direct observations made during these investigations which can substantiate such a theory, in fact, there is more evidence (Fig. 2) to suggest that the disease is closely associated with soil conditions. There has, however, never been any evidence of the disease spreading from any "focus of infection" as might be expected if caused by a soil organism.

The symptoms in the nuts and spathes represent a physiological breakdown which cannot be simply associated with the effect of a sudden drought, especially as the disease is capable of attacking palms at any time of the year, when they are known to be growing actively. Such symptoms could be due to any of the following causes:—

(*a*) A virus disease; the foliage is, however, unaffected until the disease is well advanced and then the oldest leaves are the first to change colour; there is no sign of phloem necrosis, or any other form of interference with the conductive tissues in stem and leaves which could account for the somewhat rapid death of fully grown plants. Experiments in transmission with infected materials failed.

(*b*) A root disease; this might produce some toxic effect to account for the unilateral breakdown of the nuts and spathe. On the other hand, it is strange that no symptoms of toxicity are visible in the foliage at all before this breakdown occurs. (As the disease is so localized in Jamaica, the danger of attempting inoculation experiments outside the diseased area is obvious. Such experiments have not, therefore, been carried out).

(*c*) A minor element deficiency or toxicity; it is difficult though to explain the disease affecting so many plants of all ages along the coast of Hanover within the past few years. Even so, the author is of the opinion that a difference in the geological origin of the soils in the western end of Jamaica may account for a possible difference in the minor element content of the soil throughout the area, for instance the Montpelier limestone soils in the diseased area are considered to be different to the other limestone soils distributed so widely throughout the island. It is significant also, that the disease appears to be confined to the western islands of the Caribbean. A number of minor elements were injected (in solution) into the stems of affected palms, but no cases of recovery occurred. It must be admitted, however, that such a method is of problematical value, when used without some evidence of a deficiency being first suggested by a chemical or spectrographic analysis of the plant tissues.

The nutritional status of the palm appears to be the important factor in the aetiology of the disease because (*a*) the most susceptible age at which the plants become diseased is when they reach the fruiting stage, rather than in the earlier vegetative phase (*b*) the reason for the nuts falling before leaf growth is affected may be associated with the rather striking physiological observation that the fruits are far more sensitive to a stimulus of growth, than are the leaves (Fig. 1 C) : an explanation for the cause of this difference in behaviour may give an important clue as to the cause of the physiological breakdown associated with the first symptoms of the disease, (*c*) plants vary considerably in the age at which they are affected by the disease, depending upon the type of soil on which they are growing (*d*) slow growing plants, for instance those blown down in previous hurricanes and now existing only on a very few roots, have proved resistant to the disease in otherwise completely devastated areas (Martyn) (Plate 3), on the other hand the best cultivated palms appear to be the most susceptible ones, (*e*) only one case of recovery from this disease was noted during these investigations. A bearing palm dropped all its nuts and opened a typically withered inflorescence in October, 1944; it then started to put out healthy inflorescences and retained its nuts throughout the next year when, rather significantly, this palm became diseased again at the very same time as in the previous year, namely at the beginning of October, 1945. This case of recovery, therefore, would seem to have been due more to a resistance induced by a change in the nutritional status of the palm, than to a climatic effect on the activity of a parasitic organism in the soil (one which presumably must have been established in the root system if it had been responsible for the original attack in 1944). Such a case of recovery would certainly seem to preclude the possibility of the disease being systemic.

As the leaf growth of bearing palms is not affected until they are in an advanced stage of the disease (the earlier nut-fall and internal breakdown of the spathes being symptoms which are visible two or three months before that time), it may be assumed that when the leaves of non-bearing plants show the characteristic fall in their rate of growth, they may have actually been affected by the disease for some time. On account of this, the most hopeful avenue open for investigation is to work entirely with young palm seedlings on soils where they are likely to be killed before they are two years old. With the use of such material and by maintaining constant weekly or at most, two-weekly records of leaf growth, it should be

relatively easy to examine complete root systems and carry out chemical or spectrographic analysis of whole plants *immediately* one of these small plants *starts* to slow down its growth abnormally. If not done then, the physiological breakdown of the palm is so rapid after this stage, that secondary organisms, such as *Rhizoctonia solani* and *Fusarium* spp., begin to cause rotting of the roots and bacteria attack young heart leaves causing a bud rot.

The disease seems to attack these very young palms more readily when they are kept well cultivated in the susceptible soils. An experiment has been started in Jamaica using seedling coconuts planted in a highly susceptible soil in such a way that some of their roots will soon penetrate into trenches filled with soil imported from a disease-free area of the island, while control plots have no imported soil in them.

The author is greatly indebted to Dr. E. Phillis, lately Physiologist of the Cotton Growing Corporation, Trinidad, for visiting Jamaica in March, 1945, in order to report on the physiological aspect of the disease in view of the former's opinion that the disease appears to be primarily a nutritional disorder which might be associated with some soil deficiency. During the course of his survey, Dr. Phillis suggested certain ideas for the layout of this experiment and these have been put into effect.

If the seedlings feeding in the imported soil become affected by the disease this will disprove any theory that the disease is confined to the western end of Jamaica simply because of a difference in the nutritional status of the palms growing there. Results should accrue from this experiment by the end of 1946. Small seedlings should also provide the most suitable material for testing the possibility of the disease being caused by a virus which is not readily transmitted by chemical means.

In the author's opinion a co-operative investigation by a plant pathologist and physiologist is desirable, especially in connection with the development of the disease on the seedling palms and also to ascertain the cause of the unilateral symptoms in the initial stages of the disease on bearing palms. A comparative chemical analysis of the healthy and diseased portions might supply evidence to explain this characteristic symptom of the disease.

Acknowledgments

Acknowledgment is due to the Director of Agriculture and the Coconut Marketing Board for the facilities afforded during this investigation. The Directors of Agriculture in Nassau, Trinidad and British Guiana were very helpful in arranging tours in those countries conducted by members of their Departments. The visit of Dr. E. Phillis, lately Physiologist of the Cotton Growing Corporation, provided encouragement to proceed along certain lines in the investigation. The whole-hearted co-operation of the coconut growers, who placed their estates at my disposal for purposes of observations, has been greatly appreciated. Mr. A. G. Naylor has been an invaluable assistant in helping with the field records.

Summary

1. In the past a serious disease of coconut palms in Jamaica had been considered to be the same as bronze leaf wilt in Trinidad. As a result of recent investigations, recorded in this paper, there is now no doubt that the two diseases are quite distinct. Until the cause of the disease in Jamaica is diagnosed, it is considered advisable to refer to it as the unknown disease of coconuts in that island.

2. The symptoms of the disease are described in some detail and a comparison is made between them and those of bronze leaf wilt.

3. The growth rate of the leaves, nuts and spathes of healthy and diseased palms were recorded throughout the year.

4. The effect of climate and soil conditions on the incidence of the disease is discussed. The disease affects palms far more in the wet season than in the dry season. Palms appear to be more susceptible when growth is stimulated.

5. Possible causes of the disease are referred to in brief. The author is of the opinion that the disease may be associated with a facultative root-parasite but that soil conditions are the main controlling factor in as much as they affect the nutrient status of the palms. Reasons are given for suspecting a minor element deficiency.

6. The suggestion is made that investigations should be confined largely to studying the aetiology of the disease on very young seedling palms which are known to succumb to the disease on certain soils, such plants being so much more readily handled than the larger palms.

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Postscript

Since this paper was written, the author visited the Republic of Haiti at the end of October, 1945 at the invitation of the Directeur, Department de l'Agriculture et du Travail, Damien. The presence of the disease was confirmed in the regions of Cap Haitien, Plaisance, Grand Riviere and Gonaives.

The history of the disease in Haiti is particularly interesting although it makes the problem of its cause even more perplexing. The Department de

l'Agriculture have known of its existence for the past 15 to 20 years around Cap Haitien and Port de Paix. Pierre Roumain, Attaché to the Extension Division of that Department has recently found a reference to what appears to have been the same disease in the Cap Haitien area as far back as 1880. Translating from Durand O., Rires et pleurs. Premiere partie. Ed. Carté. Imprimerie typographique (Corbeil) 1896, Roumain quotes: "On page 128 there is a footnote to a poem entitled 'The death of our "coconuts' stating that around 1880 all the "coconut palms in and in the neighbourhood of "Cap Haitien were affected by a disease which "destroyed them in a short time. The leaves "became yellow, the flowers and young nuts were "shed and only bare trunks, struck with death, "were left standing." *Note.* If the disease had been *Phytophthora* bud rot, it is extremely unlikely that *all* the coconut palms would have been killed and it was almost certainly not bronze leaf wilt because that disease has not been seen in Haiti.

As recently as 1943, the disease started at Gonaives and in the course of only two years it has destroyed all but few of approximately 8,000 bearing coconut palms in and around that town. The first bearing palms examined near the town did not show completely typical symptoms in that all the young spathes had dried without exhibiting the usual range of withered inflorescences. Later on typical symptoms were recognised near the inland border of the affected district. It is probable, therefore, that the first symptoms were due to the abnormally rapid death of the palms caused by the extreme virulence of the disease prevailing under the conditions in that district. The young plants are being killed out there faster than anywhere in Jamaica, in fact it is already difficult to find any healthy coconut palms at all in that area.

It is only within the last two years that the disease has started to appear in the Grand Riviere valley and in the district around Plaisance, both of which areas adjoin the originally affected northern plain around Cap Haitien. In neither of these new districts has the disease killed more than comparatively few plants up to the present time. It may be significant that the palms in these areas are, for the most part, scattered through the peasant coffee and banana plantations and they are therefore not so close together as were the ones killed at Gonaives. The disease has not yet been reported in the Central and Southern districts of Haiti.

The following points of interest are worthy of note in regard to the incidence of the disease in Haiti.

(i) After remaining confined to one area of the country for 60 years, where it has been gradually destroying coconuts up to the present time, the disease has just recently spread to Gonaives forty miles away.

(ii) The virulence of the disease at Gonaives has even surpassed that in the worst affected areas of Jamaica.

(iii) The disease is not confined to alkaline soils; those near Limbe are free draining and slightly acid (pH 6.8), being derived from an igneous rock formation; the soils around Gonaives are, however, highly alkaline consisting largely of a heavy, salty, calcareous, grey clay with a water table as high as eighteen inches from the surface in parts of the affected area.

(iv) Young plants on the northern plain are not affected by the disease until they reach the bearing stage, whereas at Gonaives they are affected when very much younger.

(v) Palms are affected in areas of medium rainfall (Cap Haitien, 63.8" per year) and also of very low rainfall (Gonaives, 22.2" per year).

Associated with the outbreak of the disease on coconuts at Gonaives, there has been an equally sudden and serious mortality of date palms (*Phoenix dactylifera*) and even a few royal palms (*Roystonea* (*oreodoxa*) sp.) have been killed in the same area. The first stage of disease in the date palms was not easy to discern, the lower leaves dry accompanied by withering of the inflorescences and a rotting of the heart leaves. These symptoms are very similar to those described for rhizosis of date palms in California (Bliss, D.E., 1941. "Relation of *Ceratostomella radicicola* to rhizosis of the date palm". *Phytopath*, **31**, 1123). The fungus, *C. radicicola* was associated with necrosis in the roots of affected palms. It is interesting to note, however, that "it cannot be "definitely stated that *C. radicicola* is the cause "of rhizosis, for many mature palms die suddenly "with all symptoms of rhizosis except the presence "of *C. radicicola* in the roots." On the royal palms a small amount of dieback was seen on a few branches of the inflorescence after cutting open some immature spathes.

It is impossible, at present, to say whether these palms are affected by the same disease as the coconuts but the association is, to say the least highly suggestive. The disease has never been noticed on royal palms growing in the devastated areas of Jamaica. It would seem, therefore, that the extreme severity of the coconut disease at Gonaives may be associated with a set of conditions sufficiently conducive for the disease to attack palms which are normally resistant to it. It is for that reason that Gonaives should be a particularly suitable district in which to carry out experiments, not only with coconut seedlings but with date palm seedlings as well, in order to try to elucidate the cause of the disease.

As in Jamaica, therefore, even if the disease is associated with some parasitic organism, soil conditions appear to regulate the rate of spread of the disease in any affected area, those at Gonaives being the most favourable yet encountered for its development. The existence of the disease on slightly acid soils of igneous origin tends to

militate against any theory of a soil deficiency being associated with the disease. It is of interest, however, to note that the affected area around Cap Haitien was one of the first regions in the island to be cleared and extensively cultivated by the French who developed a prosperous sugar and indigo industry there in the 18th century. There is a possibility, therefore, that the soils on that northern plain may have been depleted of some trace element before those of the surrounding inland regions which have only recently started to be affected by the disease.

On the other hand, reviewing the incidence of the disease in Haiti, it is difficult to imagine how, for instance, a soil parasite could have been suddenly introduced near Gonaives and have become so rapidly disseminated throughout the area (including the township itself) that all the coconuts have been killed within a period of only two years, especially when the land is not subjected to flooding and open drains subdivide the township into isolated blocks. Then again, if the disease is caused by a virulent windborne organism it is remarkable that it has been confined to the Cap Haitien area for so many years without spreading inland along the path of the prevailing north-east trade winds.

The sudden spread of the disease to Gonaives, forty miles away from Cap Haitien where it has been present for over sixty years, is certainly alarming in regard to the situation in Jamaica where there has been no sign of the disease spreading out of the western end of the island for forty years or more.

CHEMICAL NOTES

(Compiled by the College Department of Chemistry and Soil Science)

Manurial and cultivation experiments in Nyasaland

According to the 1944 *Report of the Nyasaland Department of Agriculture* the effect of inter-cropping tung trees for the first three or four years with maize, soya beans, velvet beans dug in annually as a green manure, and a cover crop of *Calapogonium mucunoides* has been studied for four seasons. *Calopogonium* failed to maintain itself after the third season. As judged by yield and girth of the tung trees, soya beans seems to be the best crop for interplanting, but the full effects of these treatments cannot yet be assessed. No results are yet available for manuring and spacing trials with tung.

Several experiments on pruning and spacing of tea have been made. Treatments of nursery beds of tea with two inorganic and two organic fertilizers supplying the same amounts of nitrogen showed no improvement over the unmanured control.

In an experiment on the effect of sulphate of ammonia and sulphate of potash on yield of tea, sulphate of ammonia ($\frac{1}{2}$-1$\frac{1}{2}$ ounces per bush) gave a significantly higher yield than the control, and although the yields increased with increase in application, the difference was not significant. Potash had no effect on yield and the interaction with sulphate of ammonia was insignificant.

A cultivation ex eriment laid down with tea at the end of 1941 consisted of the following treatments :—(i) hand weeding; (ii) weeds slashed down; (iii) weeds hoed and carried off; (iv) weeds hoed and buried; (v) weeds hoed and left on the surface; (vi) left unweeded.

So far the results have been inconclusive, but two outstanding points have emerged, which may be related. The first is the superiority year after year of hand-weeding, and the second is that a 'dirty' field does not seem to depress the yields as is generally supposed. Only in 1943, when the experiment was pruned early and suffered a severe set-back with the drought, did the yields drop in the unweeded plots.

In 1944 the hand-weeding treatment gave a significantly higher yield than all the treatments except (iv) and (vi), and the unweeded treatment actually gave a significantly higher yield than the hoed treatment with the weeds left on the surface; usually all the hoeing treatments give the same yield.—(*Soils and Fertilizers*, **8**, 199-200, 1945).

Leaf analysis in estimating the potassium, magnesium, and nitrogen needs of fruit trees

Leaf analyses for total potassium, magnesium and nitrogen, expressed on the dry weight basis, were found under some conditions to indicate the needs of deciduous fruit trees for these nutrients. The composition of fruit-tree leaves with respect to those three elements was also found to be influenced by the condition of the root system and conducting tissues of the tree, injuries to the leaves from toxic sprays or fertilizers, the age of the leaves, the climate, the season, ionic interrelationships, and the kind and variety of fruit tree. Data are presented to indicate the possible significance of these factors. It is concluded that chemical analysis of leaves for these constituents cannot take the place of careful observations on tree behaviour and appearance, on the development of visible leaf or fruit symptoms, and on past climatic and management conditions; but that chemical analyses of leaves, coupled with these observations, may make possible a positive diagnosis that neither alone would have permitted.—(*Soils and Fertilizers*, **8**, 255, 1945).